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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

LIMESTONES

OF

SOUTHWESTERN PENNSYLVANIA

BY

FREDERICK G. CLAPP

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

278085

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 16, 1904.

SIR: I have the honor to transmit herewith the manuscript of a paper entitled "Limestones of Southwestern Pennsylvania," by F. G. Clapp, and to recommend its publication as a bulletin.

This report deals with a subject which is of considerable interest from an economic point of view, in consideration of the recent great extension of the Portland-cement industry. The data here presented on the limestones of southwestern Pennsylvania will serve to point out promising localities for the erection of cement plants in the coal areas of the State.

Very respectfully,
C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

LIMESTONES OF SOUTHWESTERN PENNSYLVANIA.

By Frederick G. Clapp.

INTRODUCTION.

The rapid increase in Pennsylvania of Portland-cement making and of other industries based on limestone has led to a demand for information in regard to the character and occurrence of workable beds of that material in the western part of the State, and in response to this need the present paper, which contains a summary of our present knowledge regarding these beds, has been prepared. As only a comparatively small part of the field has yet been examined by the geologists of the United States Geological Survey, it is impossible to prepare anything like a final report or even to state details in all parts of the area, but by the assistance of descriptions and analyses made by the Second Geological Survey of Pennnsylvania, in addition to the more detailed work of the United States Geological Survey in the Brownsville, Connellsville, Masontown, Uniontown, Waynesburg, Latrobe, Kittanning, Rural Valley, Elders Ridge, Beaver, Indiana, Barnesboro, Patton, Curwensville, and Ebensburg quadrangles, it is possible to give considerable generalized information which it is hoped will be of economic value.

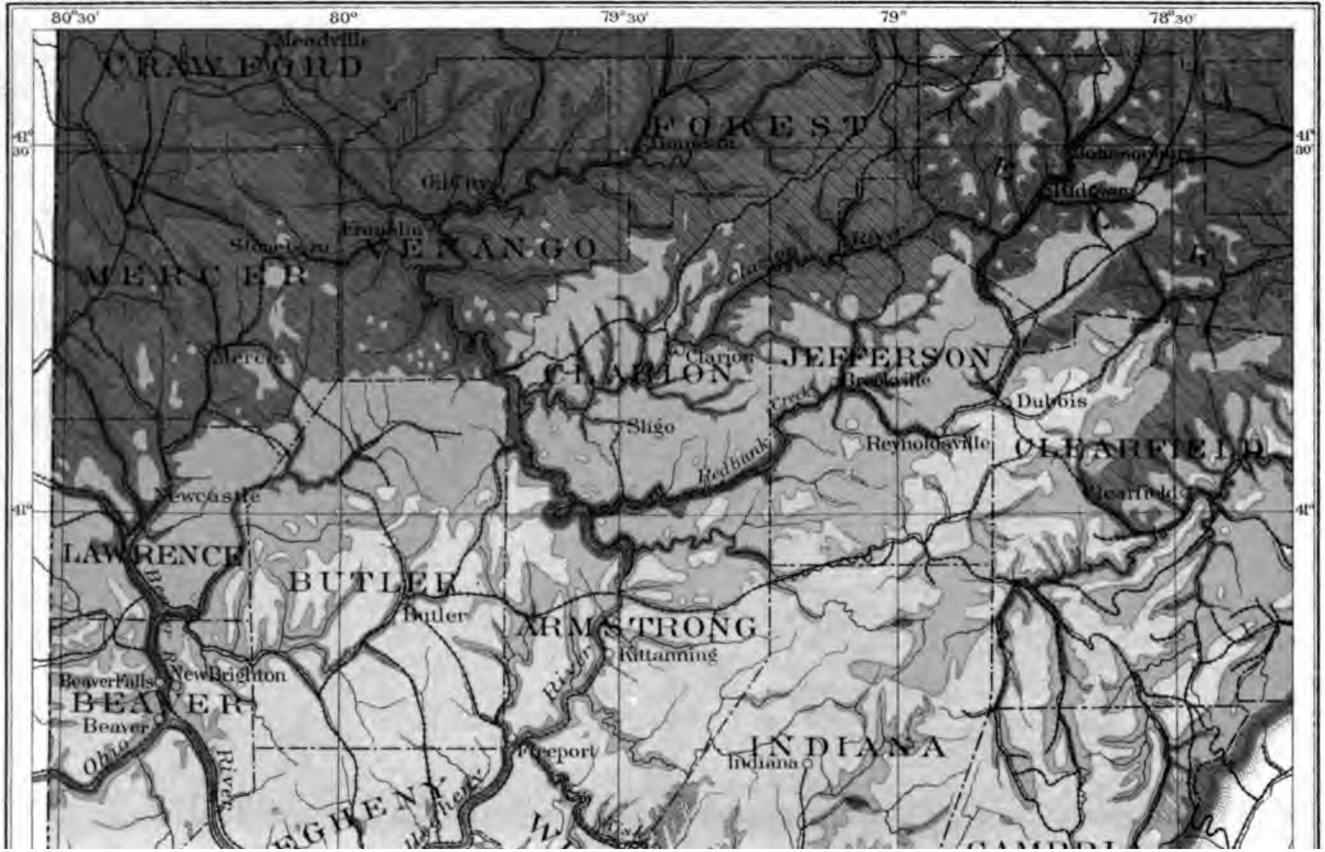
STRATIGRAPHIC DISTRIBUTION OF LIMESTONES.

The greater part of western Pennsylvania is underlain by coal-bearing rocks, in which the number of limestones is very great, though only a few of them attain workable thickness. Following is a list of the principal limestone beds, together with their maximum thicknesses and approximate stratigraphic positions:

List of principal limestones.

Formation.	Name.	Approximate stratigraphic position.	Maximum thickness.
			Feet.
Dunkard formation, or Upper Barren measures.	Upper Washington limestone (No. VI).	Top of Washington formation, 250 to 425 feet above Waynesburg coal.	30
Monongahela formation, or Upper Productive measures.	Waynesburg limestone	20 feet below Waynesburg coal.	35
	Benwood, or Great, limestone:		
	Upper member, or Uniontown, limestone.		18
	Lower member	120 feet above Pittsburg coal.	90
	Sewickley, or Fishpot, limestone.	Over 100 feet above Pittsburg coal.	30
	Redstone limestone	30 to 70 feet above Pittsburg coal.	10
Conemaugh formation, or Lower Barren measures.	Pittsburg limestone	20 feet below Pittsburg coal.	12
	Elk Lick limestone	Midway between Pittsburg and Upper Freeport coals.	6
	Ames, or Crinoidal, limestone.		8
Allegheny formation, or Lower Productive measures.	Upper Freeport limestone.	Below Upper Freeport coal.	28
	Lower Freeport limestone.	Below Lower Freeport coal.	5
	Johnstown limestone	Below Upper Kittanning coal.	10
	Vanport, or Ferriferous, limestone.	Below Lower Kittanning coal.	22
Pottsville formation	Upper and Lower Mercer limestones.	Between Homewood and Conoquenessing sandstones.	4 3
Mauch Chunk formation.	Greenbrier, or Mountain, limestone.	40 to 50 feet above bottom of Mauch Chunk.	30
Pocono formation	Loyalhanna, or Siliceous, limestone.	Upper portion of Pocono.	60
	Benezette limestones of Elk County.		7

Besides the beds named in the table there are many thin and local limestones, among which the Jollytown, Little Pittsburg, Middle Washington, and Lower Washington have been given names, but are nowhere known to be of much economic importance.


80°30'
80°
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78°30'
41° 30'
41°
CRAWFORD
Meadville
FOREST
Oil City
Franklin
VENANGO
Stoneboro
MERCER
Mercer
Clarion
River
CLARION
Clarion
JEFFERSON
Brookville
Creek
Sligo
Redbank
Reynoldsville
Dubois
CLEARFIELD
Clearfield
Ridgway
Johnsonburg
Newcastle
LAWRENCE
BUTLER
Butler
ARMSTRONG
Kittanning
River
Beaver Falls
New Brighton
BEAVER
Beaver
Ohio
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Freeport
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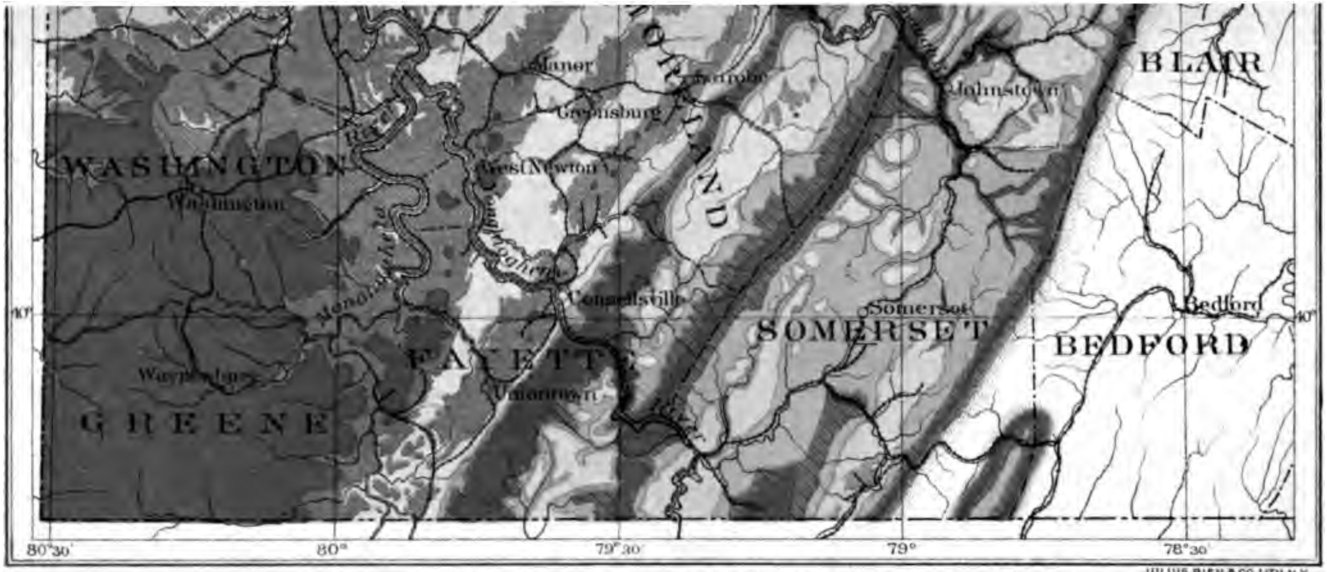

GEOLOGIC MAP OF SOUTHWESTERN PENNSYLVANIA

BY F. G. CLAPP
1904

From county atlas of the Second
Geological Survey of Pennsylvania, 1885

Scale
10 0 10 20 30 40 50 miles

LEGEND

■ Dunkard group
■ Monongahela formation
☐ Conemaugh formation
▨ Allegheny formation
■ Pottsville formation
■ Formations below Pottsville

CHARACTER AND THICKNESS.

The thicknesses given in the table are the extreme maxima known to exist, and should not be accepted as likely to occur over wide areas. The average amounts in each case are probably considerably less than half those given. In distribution the thickest beds are toward the southwest, but even there they rarely exceed a few feet, and beds averaging over 20 feet are only about three in number. Color and texture vary through wide limits, from nearly black to light gray or white, and from hard and compact, as in the Vanport (Ferriferous), to extremely fossiliferous and shaly, as in the Ames (Crinoidal). In composition all grades occur, from calcareous clays, shales, or sandstones, to limestones which contain over 96 per cent of calcium carbonate. Magnesium carbonate is always present, sometimes amounting to less than 1 per cent, but frequently rising to 10 per cent and occasionally exceeding 30 per cent. Alumina and oxide of iron may be present in any amount below 8 per cent.

All analyses given in this paper are taken from reports of the Second Pennsylvania Survey, and were mostly made in the laboratory of that survey by Mr. A. S. McCreath and his assistants. One of the most striking features in regard to nearly all the beds is their extreme variability in texture and composition, the analyses of specimens taken from the same quarry sometimes showing great extremes.[1] Variations exist in the composition of strata from the bottom, middle, and top of a bed,[2] and it is not probable that the analysis of any single specimen represents correctly the composition of the entire output from a quarry. Suitable allowance therefore must be made in accepting figures of any analysis. Another possible source of confusion in making use of analyses here given arises from the fact that all specimens analyzed were collected many years ago, and many of the farms have since changed hands and may now be known by different names. It is likewise possible that certain place names may have gone out of usage.

DESCRIPTION BY DISTRICTS.

For convenience of discussion the area is divided into four districts—Monongahela Valley, Allegheny Valley, Beaver Valley, and Allegheny Mountains. Pl. I is a general map of southwestern Pennsylvania, showing the leading geographic features and the distribution of the geologic formations. This map is compiled chiefly from the county maps of the Second Geological Survey of Pennsylvania, corrected to date.

Pls. II and V show the outcrop of the Vanport limestone so far as known.

---

[1] Leslie, P. J., and McCreath, A. S., Report of Second Geol. Survey of Pennsylvania, vol. M2, 1879, pp. 311-361, and Final Rept., vol. 1, 1892, pp. 327-338.

[2] See analyses Nos. 6, 7, 8; 35, 36, 37, 38, 39; 42, 43; 57, 58, 59; 60, 61, 62; 75, 76; 86, 87; 90, 91, 92; 97, 98, 99, on later pages.

As a rule, the limestones of each region have characteristics of their own, which would make superfluous any general preface descriptive of the individual beds. The descriptions of the horizons will therefore be placed under the headings of the several districts. Where the thickness of the bed is less than 10 feet few specific localities are mentioned, as a thin bed is of comparatively little importance.

MONONGAHELA VALLEY.

This district includes approximately the area underlain by the Pittsburg coal. From a depth of nearly sea level in the southwest corner of Greene County the coal rises rapidly toward the east and north into the hilltops, and the region therefore furnishes outcrops of all beds between the Mauch Chunk shale and the upper part of the Dunkard formation. Notwithstanding the fact that limestones are more abundant in this region than in any other portion of western Pennsylvania, only a few of the beds are of economic value. These will be discussed in their stratigraphic order.

LOYALHANNA LIMESTONE.

This bed is the Siliceous limestone of the Pennsylvania reports. It shows in outcrop only where Chestnut Ridge has been cut through by the westward-flowing streams—Conemaugh River, Loyalhanna Creek, and Youghiogheny River. It has been classed by some geologists as the basal member of the Mauch Chunk formation, but in reality is a part of the Pocono sandstone, into which it merges by insensible gradations. According to Stevenson,[1] the upper portion is a conglomeratic sandstone containing numerous fragments of siliceous limestone. This portion grades gradually into the siliceous limestone proper, which is a fine-grained rock having a blue color, flint-like fracture, and no true cleavage. On its fresh surface it shows no signs of bedding, but where exposed for some time takes on a dull brown color and shows a peculiar cross-bedding. The weathered surface is very characteristic, being rough and pitted and unlike any other rock in the region. This feature is well illustrated by the photograph, Pl. VII, *B*. The large proportion of silica in the rock gives it the general appearance of a sandstone rather than of a limestone.

The Loyalhanna limestone is of greatest importance northward, being on Conemaugh River between 40 and 50 feet thick in both gaps. A similar thickness prevails in the Loyalhanna and Youghiogheny gaps, but southward the rock becomes thinner, being only about 18 feet thick on the National Pike and barely 4 feet near the State line. On Cheat River, West Virginia, it has wholly disappeared.

The limestone often occurs in two benches, separated by shale and sandstone. At a number of points it has been quarried for paving blocks and crushed for railroad ballast. Large crushing plants have been established on Conemaugh River above Blairsville, in the Loyalhanna gap above Latrobe, and in the Youghiogheny gap above Connellsville. At the last-mentioned place the quarry face has a height of 60 feet, but a part of the thickness should probably be classed as sandstone.

---

[1] Report K3, p. 52.

GREENBRIER LIMESTONE.

This is the Mountain limestone of the Second Geological Survey reports, and is the feather-edge of the Greenbrier of Virginia and probably of the Chester and St. Louis beds which occur in the Mississippi Valley, where they attain great thickness. Its greatest development in Pennsylvania is along the southern boundary of the State, where it attains a thickness of about 40 feet. Along Chestnut Ridge and Laurel Hill it outcrops about 50 feet above the Loyalhanna limestone. The Greenbrier is somewhat variable in character, the greater part being composed of thin beds of pure blue limestone, which often grade into shaly limestone and calcareous shale. In places it is very fossiliferous. No analyses are known to have been made. Its principal use is in burning for fertilizer, for which purpose it is said to yield lime of superior quality. Formerly it was used as a flux in iron smelting.

UPPER FREEPORT LIMESTONE.

This is the only limestone of the Allegheny formation known to occur in the region. It is rarely seen and may not be persistent, but is known in places to reach a thickness of 5 feet. The following analyses[1] have been made:

Analyses of Upper Freeport limestone from Westmoreland County, Pa.

	No. 1.[a]	No. 2.[b]
Insoluble residue	0.990	4.015
Calcium carbonate ($CaCO_3$)	94.643	91.982
Magnesium carbonate ($MgCO_3$)	1.144	1.664
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.720	1.520
Sulphur	.028	.091
Phosphorus	.015	.012

[a] Second Geol. Survey of Pennsylvania, vol. M2, 1875, p. 293.

[b] Second Geol. Survey of Pennsylvania, vol. H4, 1878, pp. 245-246; analysis by D. McCreath.

No. 1.—From Kier Brothers' quarry at Salina: Fine grained, brittle; reddish gray; conchoidal fracture.

No. 2.—From Wining & Cuisan's quarry, one-half mile northwest of Kellys Station: Compact, brittle; pearl gray; conchoidal fracture; sparkles with calcite; thickness of bed, reported 4-5 feet.

---

[1] All the analyses given in this paper are taken from the reports of the Second Geological Survey of Pennsylvania, and were made in the laboratory of that survey by Mr. A. S. McCreath and his assistants. Where the name of the analyst is known it is given in a footnote.

PITTSBURG LIMESTONE.

Several limestone horizons occur in the Conemaugh formation, but are only locally represented by limestone. They rarely attain a thickness of 4 feet and are unimportant, being used only for fertilizing purposes. Following is an analysis of the Pittsburg limestone—a bed occurring approximately 20 feet below the Pittsburg coal; the specimen was taken from a quarry at Lemont furnace, 3 miles northeast of Uniontown:

Analysis of Pittsburg limestone from Fayette County, Pa.[a]

	No. 3.
Insoluble residue	7.360
Calcium carbonate ($CaCO_3$)	87.868
Magnesium carbonate ($MgCO_3$)	1.733
Ferrous carbonate ($FeCO_3$)	1.914
Alumina (Al_2O_3)	.135
Sulphur	.106
Phosphorus	.050

[a] Vol. M2, p. 290.

No. 3.—Comparatively soft and brittle; very irregular fracture; bluish-gray color.

REDSTONE LIMESTONE.[1]

This is a hard, gray, crystalline limestone of some value, occurring below the Redstone coal and 30 to 70 feet above the Pittsburg coal. Its principal occurrence is in the Connellsville basin, where it is rather persistent. On Redstone Creek and in the territory between this stream and Allegheny River it is of fair thickness and excellent quality, and throughout Fayette County has been quarried extensively in the past for fluxing purposes to the exclusion of all other limestones. For the same purpose it is extensively quarried in the vicinity of Wheeling, W. Va.[2] Throughout the greater part of the Monongahela Valley it is usually absent or very impure. The following analysis of the stone from the quarry at Lemont furnace indicates that if the composition given is characteristic of the bed, the percentage of magnesia is too great to allow of its having any value for Portland cement:

---

[1] Vol. K2, pp. 48-49.

[2] White, I. C., Stratigraphy of the bituminous coal fields of Pennsylvania, Ohio, and West Virginia: Bull. U. S. Geol. Survey No. 65, 1891, p. 63.

Analysis of Redstone limestone from Fayette County, Pa.[a]

	No. 4.
Insoluble residue	9.460
Calcium carbonate ($CaCO_3$)	66.471
Magnesium carbonate ($MgCO_3$)	17.711
Ferrous carbonate (Fe_2O_3)	5.178
Alumina (Al_2O_3)	.812
Sulphur	.080
Phosphorus	.048

[a] Vol. M2, p. 289.

No. 4.—Hard and brittle; sparkles with calcite; pearl gray; conchoidal fracture.

SEWICKLEY LIMESTONE.[1]

This is the Fishpot limestone of early reports. It underlies the Sewickley coal at an interval of about 15 feet, and has its best known development in the Connellsville basin. Toward the south it is thin and of inferior quality, improving northward, but always of irregular occurrence. The greatest thicknesses reported are from 30 to 35 feet, in the vicinity of Greenfield on Monongahela River; on Redstone Creek, in Jackson Township, Fayette County, where it is the chief source of lime for agricultural purposes, and at Brownsville. It is reported to have been quarried for use as a flux in North Union Township, Fayette County, but generally it runs too high in silica for this purpose. The following analysis shows the quality of the stone at Oliphant furnace, in Georges Township, Fayette County:

Analysis of Sewickley limestone from Fayette County. Pa.[a]

	No. 5.
Insoluble residue	10.770
Calcium carbonate ($CaCO_3$)	80.647
Magnesium carbonate ($MgCO_3$)	2.217
Ferrous carbonate ($FeCO_3$)	1.657
Iron disulphide (FeS_2)	1.125
Alumina (Al_2O_3)	.543
Sulphur trioxide (SO_3)	.052
Phosphoric oxide (P_2O_5)	.066
Water	1.010
Carbonaceous matter	1.250

[a] Vol. M2, p. 287.

No. 5.—Compact; minutely crystalline; spotted with pyrite; dark blue.

---

[1] Vol. K2, pp. 44-46.

If the bed maintains this composition it ought to be of value in the manufacture of Portland cement, and that such may be the case is indicated by the analysis of the same bed in Indiana County. Analyses from Somerset County give a larger percentage of magnesia, proving that the stone at those points is unsuitable for the purpose.

BENWOOD LIMESTONE.[1]

The Benwood, or Great, limestone is by far the most important limestone in the Monongahela Valley. It sometimes amounts, with its interbedded shales, to as much as 140 feet in thickness, and is present throughout nearly all the area in which the Monongahela formation outcrops. It is a double limestone, occurring between the Uniontown and Sewickley coal beds and about 120 feet above the Pittsburg coal. In the vicinity of the Pennsylvania Railroad its stratigraphic position has given it locally the name of the "120-foot limestone." The upper member, known as the "Uniontown limestone," is usually 6 to 15 feet in thickness, often impure and of a buff color, and is said to be a good natural cement rock. At Uniontown the bed is 10 feet in thickness, and has been quarried extensively for natural cement, used in the construction of the locks on Monongahela River. There are reported thicknesses of 40 feet on the West Newton pike, in Rostraver Township, Westmoreland County; of 15 feet at Markles Mill, on Sewickley Creek, and of 14 feet near Round Hill Church, in Elizabeth Township, Allegheny County.

The lower member is much more persistent than the Uniontown bed. It varies in character from a hard and pure to a very shaly limestone. It is much thicker than the Uniontown bed, usually averaging above 50 feet. The maximum thickness is reached along Monongahela River, where it is sometimes as much as 90 feet. On Sewickley Creek near Bells Mills it is 85 feet or more, and on Youghiogheny River near the Westmoreland County line, 55 feet. Toward the north it diminishes in thickness, and, where it is exposed along the Pennsylvania Railroad, varies between 7 and 28 feet. Occasionally the bed is one solid mass of limestone, but throughout the greater part of the region it is broken up into a number of strata separated by shale. The rock is often siliceous or argillaceous and sometimes ferruginous. Where extensively weathered it has become broken up into small angular fragments. The bottom of the member is said to be generally the more magnesian, although all portions are extremely high in magnesia, as indicated by the first three of the following analyses, and is nowhere known to be suitable for Portland cement. In Washington County the stone was considerably used in early days in the manufacture of natural cement.

---

[1] Vol. K2, pp. 37-40.

Analyses of Benwood limestone from Washington County, Pa.

	No. 6.[a]	No. 7.[b]	No. 8.[b]	No. 9.[c]
Insoluble residue	13.300	22.520	15.750	14.920
Calcium carbonate ($CaCO_3$)	68.837	48.823	47.080	47.750
Magnesium carbonate ($MgCO_3$)	14.649	20.621	28.528	30.943
Ferrous carbonate ($FeCO_3$)	3.306	3.625	7.511	5.608
Alumina (Al_2O_3)		3.523		
Sulphur	.097	.203	.069	.126
Phosphorus	.049	.051	.127	.015

[a] Vol. K, 1876, p. 388; analysis by A. S McCreath.
[b] Loc. cit.; analysis by D. McCreath.
[c] Vol. M2, p. 285; analysis by D. McCreath.

No. 6.—One mile north of Canonsburg: Upper layer, very hard and compact, like conglomerate, bluish gray.

No. 7.—One mile north of Canonsburg: Middle layer, compact, somewhat shaly, color bluish gray.

No. 8.—One mile north of Canonsburg: Lower layer, hard, compact, unctuous, pearl gray.

No. 9.—Property of Dr. Shaner, in Somerset Township, 8 miles from Washington.

WAYNESBURG LIMESTONE.[1]

The Waynesburg limestone, which is a rock of good quality, with a probable maximum thickness of about 20 feet, occurs a short distance below the Waynesburg coal. On Redstone Creek, in Franklin and Redstone townships, it amounts to 15 or 20 feet. On Browns Run, in German Township, Fayette County, it is reported by Stevenson as swelling to 35 feet; but elsewhere such a thickness is unknown. The common thickness varies between 8 and 15 feet. The stone makes a strong but rather dark lime. It is accessible at many places throughout Fayette, Westmoreland, eastern Greene, and southeastern Washington counties.

LIMESTONES OF THE DUNKARD FORMATION.

Scattered throughout the Dunkard formation are abundant limestone beds, which have been described by the Second Survey and numbered from I to XIV inclusive.[2] At the time this bulletin is submitted these have not been studied by the present survey, but from Stevenson's investigations it appears that few of them are of sufficient thickness or quality to be of value. The following table, compiled from the descriptions given in Volume K, gives the principal features of the several beds:

---

[1] Vol. K2, pp. 85-86.

[2] Stevenson, Vol. K.

Tables of limestones in the Dunkard formation.

[Abstracted from Vol. K, Stevenson, 1875.]

Stevenson's name.	Other names.	Approximate stratigraphic position.	Maximum thickness, in feet.	Characteristics.	General distribution.	Localities of extreme thickness.
XIV		80 feet above limestone XIII.	8	Dark blue; earthy; minute crystals of blende and occasional fish scales.	Scattered localities in western Greene County.	
XIII		Below Gilmore sandstone.	4	Dull blue; earthy; with shale	do	Browns Fork 1 mile above Ninevah, Greene County; mass of limestone and shale 15 feet.
XII		230 feet above Upper Washington limestone.	15	Usually thin; contains much shale.	Western Greene and southwestern Washington counties.	Head of Robinsons Fork, East Finley Township, Washington County; 8 feet.
XIa XIb			2½			Very local limestones.
X		100 feet above limestone IXb.	5	Dark blue and earthy; sometimes brecciated.	Western Greene and southwestern Washington counties.	
IXa		70 to 100 feet above limestone VIII.	10	Usually very impure	Southwestern Greene County.	McCourtneys Fork below White Cottage; 6 to 8 feet. Grays Fork at mouth of Scotts Run; 6 to 10 feet. Clover Run.
IXb			10	do	do	
VIII				Impure and not persistent		
VII				Usually earthy	Central Greene County	
VI	Upper Washington limestone.	Top of Washington formation.	30	Usually pure; usually weathers snowy white; color generally dark blue-gray.	Washington and Greene counties.	See page 20.
V	Jollytown limestone.[a]	20 to 30 feet below Upper Washington limestone.	10			
IV	Middle Washington limestone.	40 to 70 feet above Washington coal.	15	Hard and coarsely brecciated; weathers to dull gray, tinged with yellow.	Washington and Greene counties.	
III			8	Massive; fresh fracture glistens with calcite; weathers rusty yellow; very fossiliferous.	Washington County	

II	Lower Washington limestone.	6 to 20 feet above Washington coal.	8	Light blue to buff	Washington and Greene counties.	
Ib	....	2 to 10 feet below the Little Washington coal.	20(?)	Dark blue; weathers bluish white; slaty structure.	Everywhere accompanies the Washington coal.	About 2 miles north of Williamsport pike, near west border of South Strabane Township, Washington County; 8 feet.
Ia	Colvins Run limestone [b]	Between Waynesburg A coal and Waynesburg B coal.	10	Massive, compact; very impure; exfoliates on weathering; sometimes brecciated and ferruginous.	Greene and Washington counties.	

---

[a] White, I. C., in Bull. U. S. Geol. Survey No. 65, 1891, p. 34, defines the Jollytown limestone as a bed occurring at an interval of 25 to 30 feet below the Dunkard coal; Stevenson's usage, however, has the priority of sixteen years.

[b] White, I. C., op. cit., p. 39.

UPPER WASHINGTON LIMESTONE.

This is the principal and only important limestone bed of the Dunkard formation. It occurs 250 to 425 feet above the Waynesburg coal, and is widely distributed throughout Greene and Washington counties. It is usually easily recognized by its weathered surface, which is almost snowy white, with a slight tinge of blue. Throughout the greater part of Washington County the rock has, on fresh fracture, a very dark blue-gray to bluish black color, which is to be considered characteristic of the bed. It varies in thickness from 4 to 15 feet, but greater thicknesses are occasionally reported. The tunnel of the Baltimore and Ohio Railroad, about 1 mile east of Washington, cuts through the bed, exposing nearly 20 feet of solid limestone. A section on Cemetery Hill, near Washington, is reported to show a mass of limestone and shale 30 feet 3 inches in thickness, subdivided as follows:

Section of Upper Washington limestone near Washington, Pa.[1]

	Ft.	In.
Limestone, laminated, argillaceous	2	0
Dark shale	5	0
Calcareous shale	6	0
Shale with vegetable markings	2	0
Limestone	0	10
Bituminous shale	0	10
Limestone	2	0
Calcareous shale	1	3
Limestone	1	6
Shale	0	10
Limestone	3	0
Shale	2	0
Limestone	3	0
Total thickness	30	3

The stone has been burned in many places for a fertilizer. Following is an analysis of a sample from the railroad tunnel east of Washington, which indicates that if the quality of the stone is constant it should be of fair quality for the manufacture of cement. At this point the bed consists of nearly 20 feet of solid limestone.

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[1] Vol. K, p. 46.

Analysis of Upper Washington limestone near Washington, Pa.[a]

	No. 10.
Insoluble residue	17.380
Calcium carbonate ($CaCO_3$)	72.866
Magnesium carbonate ($MgCO_3$)	3.813
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.929
Sulphur	.155
Phosphorus	.061

[a] Op. cit., p. 388; analysis by D. McCreath.

No. 10.—From middle of bed; hard, compact, bluish-gray limestone; conchoidal fracture.

ALLEGHENY VALLEY.

This region includes the lower portion of the Allegheny Valley and its tributaries, underlain principally by rocks of the Pottsville, Allegheny, and Conemaugh formations. Isolated patches of the Monongahela, however, occur in the southern portion, and in the northern part the Pocono and Mauch Chunk rise above water level. The limestones range from those of the Pocono formation up to the Sewickley.

BENEZETTE LIMESTONE.

At a few points in Elk County a triple bed of limestone, supposed to be of Pocono age, has been found about 200 feet below the Olean conglomerate. The upper bed is reported as having a probable maximum thickness of not over 7 feet, the others being considerably thinner. The lower bed has been burned, and is said to make an excellent fertilizer. Analyses have been made of the upper and middle beds, specimens of which were taken from a point on Caledonia road 1 mile west of the village of Benezette.

Analyses of Benezette limestone from Elk County, Pa.[1]

	No. 11.	No. 12.
Siliceous matter	50.670	15.980
Calcium carbonate ($CaCO_3$)	36.785	76.143
Magnesium carbonate ($MgCO_3$)	1.408	1.740
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	10.070	3.680

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[1] Vol. M3, 1881, p. 93.

MERCER (TIONESTA) LIMESTONE.

This is of uncertain occurrence, but is known to be present at a few points. An analysis has been made of a specimen from Kelly's quarry on the Saddle Bags tract, 4 miles east of Tionesta, on Tionesta Creek, Forest County, where the thickness is from 2 to 3 feet.

Analysis of Mercer limestone from Forest County, Pa.[a]

	No. 13.
Siliceous matter	55.160
Calcium carbonate ($CaCO_3$)	40.642
Magnesium carbonate ($MgCO_3$)	1.172
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.120
Phosphorus	.018

[a] Op. cit., p. 90.

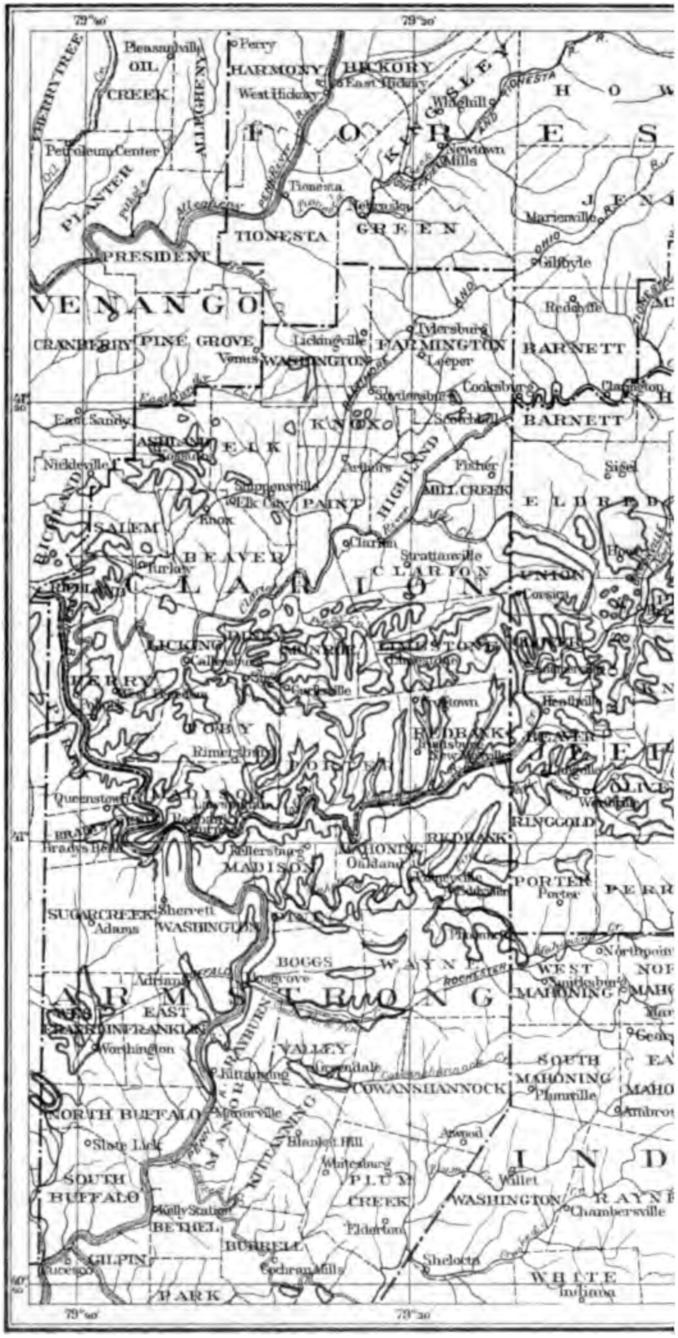
No. 13.—Coarse grained; appearance sandy; very hard and tough; bluish gray.

VANPORT LIMESTONE.

This bed, usually known as the Ferriferous, is without doubt the most widespread and available limestone for Portland-cement manufacture in western Pennsylvania, outcropping over large parts of Jefferson, Clarion, Armstrong, northern Butler, and Lawrence counties, and appearing occasionally in northern Indiana, Beaver, and Venango counties, but dying out along a line drawn in a northeast-southwest direction through the middle of Indiana and the western part of Clearfield counties. Although not always present, even in those counties where it is best developed, it is the most persistent stratum known in western Pennsylvania, and therefore a good key to the geologic structure. The approximate outcrop in the Allegheny Valley is shown on Pl. II. In stratigraphic position it occurs below the Lower Kittanning coal and fire clay, from which it is sometimes separated by sandstone, but more often by a thin bed of limonite, known as the "buhrstone ore bed."

The limestone is of good quality throughout. It is usually compact and brittle, with an irregular fracture, and has a grayish color. It is occasionally very fossiliferous, containing a genuine marine fauna, consisting of crinoids, corals, brachiopods, lamellibranchs, univalves, etc. The maximum known thickness is 22 feet. This limestone, as shown by analyses, is the only bed in western Pennsylvania which almost universally contains less than 2 per cent of magnesium carbonate. The only specimen of this bed containing more magnesium carbonate is from Benezette, Elk County, and shows over

U. S. GEOLOGICAL SURVEY



MAP OF A PORTION OF THE AL

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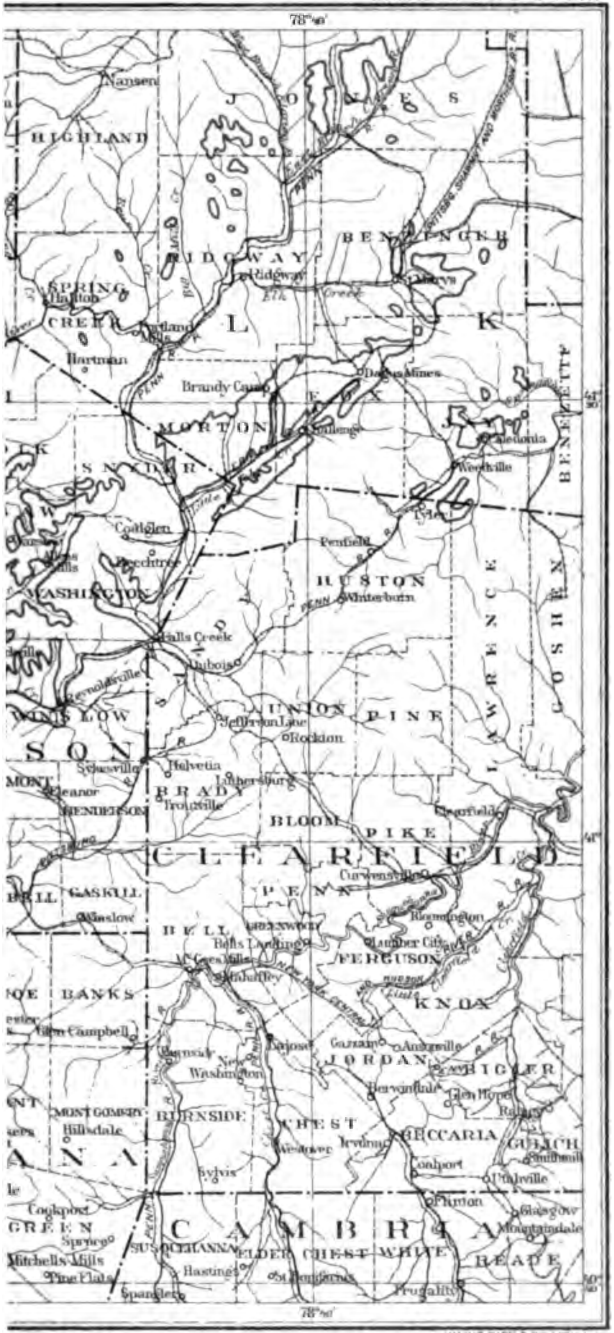


JULIUS BIEN & CO. LITH N.Y.

NY VALLEY AND VICINITY
RT LIMESTONE

From a map published by the Second Geological Survey of Pennsylvania 1893

10 20 miles

6 per cent. The siliceous matter is likewise usually very low, while the proportion of calcium carbonate is high, running between 86 and 96 per cent. The stone is now used for the manufacture of Portland cement at one plant, and there is every reason to believe it will be extensively used for this purpose in the future. It also makes excellent ballast, flux, road metal, and fertilizer.

Indiana County.—Four feet five inches of the Vanport limestone was penetrated by a diamond-drill hole on Ramsay Run, and its outcrop is found at one point on the north side of Yellow Creek; but with these exceptions the bed is known only in the northern part of the county, where it outcrops on Mahoning Creek with a thickness of 4 or more feet. A specimen from Isaac Simpson's quarry, one-half mile southwest of Richmond, gave the following analysis:

Analysis of Vanport limestone from Indiana County, Pa.[a]

	No. 14.
Insoluble residue	2.090
Calcium carbonate ($CaCO_3$)	92.857
Magnesium carbonate ($MgCO_3$)	1.589
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.030
Sulphur	.187
Phosphorus	.035

[a] Vol. H4, p. 264.

No. 14.—Hard and tough; fossiliferous; fracture irregular; color, dark bluish gray.

Armstrong County.—In the southern part of Armstrong County outcrops of the limestone are only occasional, but from Kittanning northward the horizon is above water level along Allegheny River and appears in several of the larger side valleys. Pl. III, from a photograph taken at the Kittanning Clay Manufacturing Company at Kittanning, shows a section included between the bottom of the Vanport limestone and the top of the Lower Kittanning coal. The limestone and coal are here separated by a few inches of buhrstone ore and 15 to 30 feet of shale and fire clay. Pl. IV, *A* and *B*, are nearer views of part of the quarry. The buhrstone ore bed is the dark stratum beneath the shovel in Pl. IV, *B*.

At Mahoning the limestone is quarried and shipped to Kittanning, where it is used by the Kittanning Iron and Steel Manufacturing Company as a flux. At West Winfield, on the edge of Butler County, the bed has a thickness of 21 feet. It is extensively mined and shipped by A. G. Morris, who is working practically the whole thickness and has probably the largest limestone quarry in western Pennsylvania. Analyses of stone from this vicinity are wanting, but several have been made from points throughout Armstrong County. The usual thickness is only from 6 to 10 feet, as shown in the following table:

Analyses of Vanport limestone from Armstrong County, Pa.

	No. 15.[a]	No. 16.[b]	No. 17.[c]	No. 18.[d]	No. 19.[e]	No. 20.[f]	No. 21.[g]
Insoluble residue	3.420	0.790	2.100	0.370	2.110	3.220	2.800
Calcium carbonate ($CaCO_3$)	93.246	96.007	94.185	96.785	95.567	93.292	94.721
Magnesium cabonate ($MgCO_3$)	1.740	1.498	1.483	1.278	1.422	.968	1.044
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	1.667	1.462	2.089	1.000	.930	1.718	1.383
Sulphur				.060			
Phosphorus	.032	.034	.03	.029	.035	.047	.047
Thickness in feet	8 to 10	9	7	8			

[a] Vol. H5, p. 97; analysis by McCreath.
[b] Op. cit., p. 169; analysis by McCreath.
[c] Op. cit., p. 64; analysis by McCreath.
[d] Vol. M2, p. 298.
[e] Vol. M3. p. 85.
[f] Op. cit., p. 86.
[g] Op. cit., p. 85.

No. 15.—Cowanshannock Creek, west edge of Cowanshannock Township: Coarse; grayish; very fossiliferous.

No. 16.—Mahoning Creek, at Stewardson Furnace.

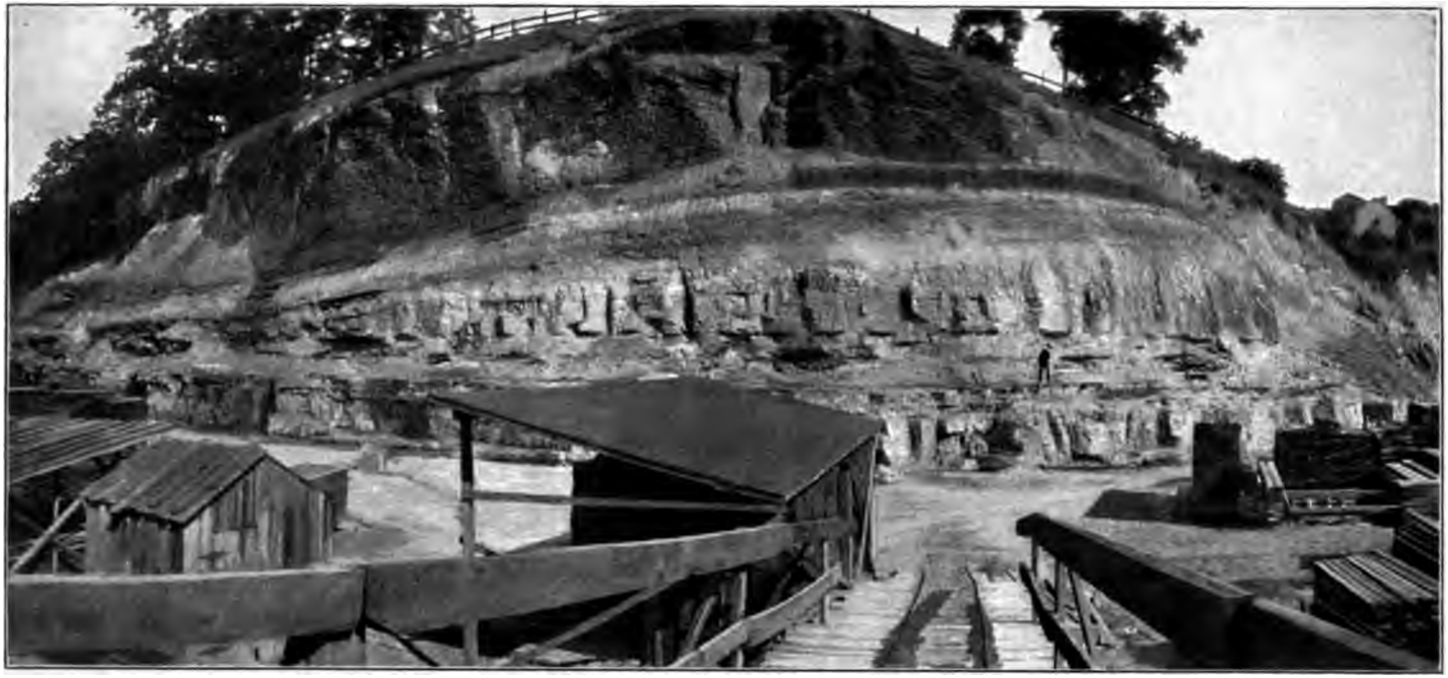
No. 17.—Crooked Creek, between Mr. George's and pottery: Bluish gray; compact; brittle: richly fossiliferous; the lime is dark, but good, breaking down into a soft fine powder.

No. 18.—Pine Creek furnace, 6 miles northeast of Kittanning: Compact; bluish gray; irregular fracture.

No. 19.—Ross Reynold's limestone, one-half mile north of Kittanning: Fine grained; fossiliferous; mottled with calcite; rather tough: light pearl gray.

No. 20.—P. Graff, near Buffalo Mills: Fine grained: brittle; more or less stained with ferric oxide; fracture rough, somewhat conchoidal; color, dark gray.

No. 21.—J. A. Colwell's quarry, one-fourth mile northwest of Mahoning furnace: Rather compact and fine grained, full of fossil casts; bluish gray; conchoidal fracture.



VANPORT LIMESTONE IN QUARRY OF KITTANNING CLAY MANUFACTURING COMPANY, KITTANNING, PA.

(Photograph by M. R. Campbell.)

Following is a more detailed analysis of a specimen from Stewardson furnace, 1 mile east of the mouth of Madison Creek, in Madison Township:

Analysis of Vanport limestone from Stewardson furnace, Armstrong County, Pa.[a]

	No. 22.
Calcium carbonate ($CaCO_3$)	95.535
Magnesium carbonate ($MgCO_3$)	.907
Silica (SiO_2)	2.030
Alumina (Al_2O_3)	.174
Ferric oxide (Fe_2O_3)	1.114
Manganic oxide (Mn_2O_3)	.206
Sulphur trioxide (SO_3)	.064
Phosphoric oxide (P_2O_5)	.082
Water	.150

[a] Vol. M3, p. 85.

No. 22.—Fine grained; full of fossil casts; pearl gray to reddish gray; fracture rough, slightly conchoidal.

Clarion County.—According to the Second Survey, although the limestone is sometimes absent over wide areas, it has nevertheless more than 450 linear miles of outcrop in Clarion County. The thickness averages about 8 feet in the western townships and occasionally runs as high as 15 feet. In the past the stone has been considerably used as a furnace flux. Four analyses have been made, as follows:

Analyses of Vanport limestone from Clarion County, Pa.[a]

	No. 23.	No. 24.	No. 25.	No. 26.
Insoluble residue	1.110	1.780	1.960	2.190
Calcium carbonate ($CaCO_3$)	96.428	95.196	95.532	95.232
Magnesium carbonate ($MgCO_3$)	1.202	1.265	.930	.407
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	.867	1.529	1.050	1.310
Phosphorus	.023	.081	.070	.061

[a] Vol. M3, p. 87.

No. 23.—Barger quarry, Perry Township: Rather coarse grained; mottled with calcite; bluish gray.

No. 24.—Sligo furnace, Piney Township: Fine grained; rather tough; stained with ferric oxide; light bluish gray.

No. 25.—Hindman's quarry, Clarion Township: Fine grained; mottled with calcite; rather brittle; bluish gray.

No. 26.—On Long Run, Porter Township: Brittle; more or less stained with ferric oxide; generally pearl gray; bed 5 to 6 feet thick, overlain by 9 inches of carbonate ore.

Jefferson County.—Over three-fourths of Jefferson County the bed has extensive outcrops, with a maximum thickness of from 4 to 6 feet; but toward the southeast it dies out entirely, and in Clearfield County is unknown.

Analyses of Vanport limestone from Jefferson County, Pa.

	No. 27.[a]	No. 28.[b]	No. 29.[b]	No. 30.[b]
Insoluble residue	1.280	1.300	1.910	2.040
Calcium carbonate ($CaCO_3$)	96.578	96.428	94.392	93.643
Magnesium carbonate ($MgCO_3$)	.832	.908	1.702	1.816
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	.780	.990	1.315	1.310
Phosphorus	.037	.034	.031	.030

[a] Vol. M3, p. 90.

[b] Op. cit., p. 89.

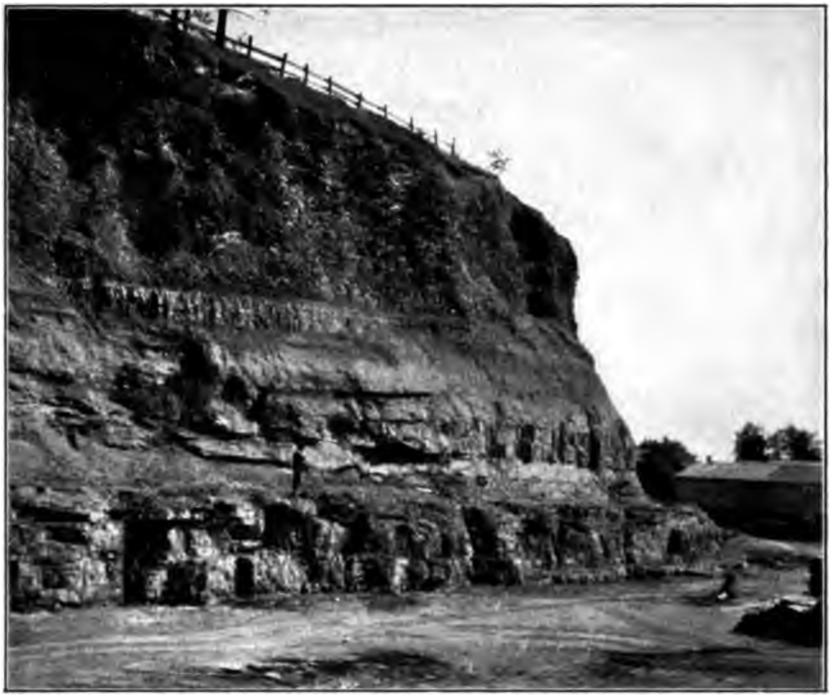
No. 27.—Samuel Shield's property, 1 mile north of Dowlingville: Rather fine grained; fossiliferous; sparkles with calcite; pearl gray.

No. 28.—Property of A. Enty, one-half mile southeast of Worthville: Fine grained; brittle; fossiliferous; light bluish gray.

No. 29.—C. Bovaird, 3 miles northwest of Brockwayville: Fine grained; brittle; pearl gray.

No. 30.—Property of William Hanna, 2 miles northeast of Sprankles Mills: Hard and tough; fine grained; full of fossil casts; dark bluish gray.

Elk County.—Little is known of the limestone in this county, but from analyses made by the Second Survey it is thought to be more variable in quality than in any other portion of the region. It is here known as the Clermont limestone, has a maximum thickness of from 7 to 10 feet, and has been quarried on a small scale.



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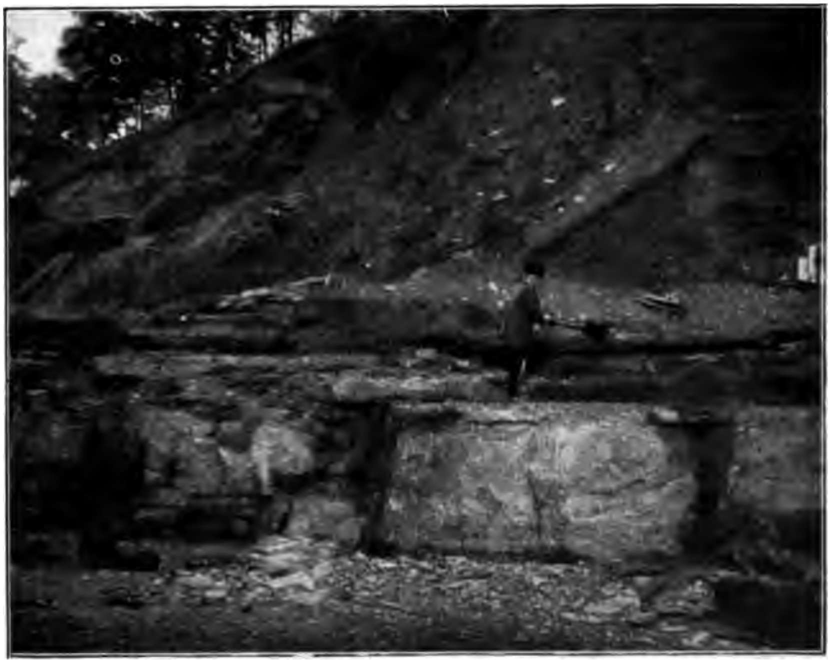

B

VANPORT LIMESTONE IN QUARRY OF KITTANNING CLAY MANUFACTURING COMPANY, KITTANNING, PA.

(Photographs by M. R. Campbell and Charles Batts.)

Analyses of Vanport limestone from Elk County, Pa.

	No. 31.[a]	No. 32.[b]	No. 33.[a]	No. 34.[b]	No. 35.[b]	No. 36.[b]	No. 37.[b]	No. 38.[b]	No. 39.[b]
Insoluble residue	2.390	8.390	3.370	7.370	1.630	2.200	61.670	38.950	41.690
Calcium carbonate ($CaCO_3$)	86.910	85.714	91.785	86.214	94.357	94.107	27.857	54.553	49.732
Magnesium carbonate ($MgCO_3$)	6.659	1.170	1.808	1.785	1.634	1.369	.983	1.135	1.331
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.205	3.422	1.710	2.610	1.638	1.626	3.830	3.030	3.650
Phosphorus	.017	.069	.032	.050	.031	.063	.062	.104	.238

[a] Vol. M3, p. 91. [b] Op. cit., p. 92.

No. 31.—G. W. Winslow's farm, 2 miles northeast of Benezette: Rather coarse grained; brittle; mottled; thickness, 10 feet.

No. 32.—Kylers Corner, Fox Township, on east side of Little Toby Creek: Very fine grained; brittle; fracture conchoidal; color, bluish gray.

No. 33.—Brandy Camp post-office, Horton Township: Rather coarse grained; brittle; mottled with calcite: bluish gray.

No. 34.—One mile east of J. S. Chamberlain's farm, from branch of Toby Creek, Fox Township: Very fine grained and brittle; fracture, subconchoidal; dark bluish gray.

No. 35.—General Kane's quarry, Jones Township; Johnson Run coal basin, 4 miles east of Wilcox (upper bed): Fine grained and very brittle; more or less stained with iron oxide; reddish gray.

No. 36.—General Kane's quarry, Jones Township; Johnson Run coal basin, 4 miles east of Wilcox (lower bed): Rather fine grained; brittle; mottled with calcite; dark bluish gray.

No. 37.—Oyster's quarry, Brockport, Horton Township (middle bed): Fine grained; brittle; argillaceous; dark blue.

No. 39.—Oyster's quarry, Brockport, Horton Township: Appearance, shaly; fossiliferous; bluish black; thickness in this quarry, 7 feet or more.

JOHNSTOWN LIMESTONE.

This is an impure limestone occurring directly beneath the Upper Kittanning coal and fire clay. Although it has been observed at widespread localities throughout the western part of the State, it is not supposed to be at all persistent, as it is frequently known to give way to ore-bearing shales, and sometimes disappears entirely. On account of having been used for natural cement at its type locality at Johnstown, the limestone has hitherto been known as the Johnstown cement bed. The composition, however, is extremely irregular, the calcium carbonate varying anywhere between 34 and 92 per cent and the magnesium carbonate from 1.4 to 21 per cent. This variation renders the term "cement rock" hardly appropriate, and the word "limestone" is therefore substituted. The frequent large percentage of silica and other impurities is illustrated by the following analysis:

Analysis of Johnstown limestone from the type locality at Johnstown, Pa.[a]

	No. 40.
Insoluble residue	27.873
Calcium carbonate ($CaCO_3$)	34.301
Magnesium carbonate ($MgCO_3$)	21.650
Ferrous carbonate ($FeCO_3$)	8.700
Alumina (Al_2O_3)	3.390
Iron disulphide (FeS_2)	1.268
Phosphorus	.049

[a] Vol. H2, p. 153.

No. 40.—Hard and brittle; bluish gray; shows considerable pyrites; emits strong argillaceous odor when breathed upon.

On Black Lick Creek the bed is reported to be extensively quarried and to have a thickness of 10 feet. In this region and still farther east it was formerly supposed to be identical with the Ferriferous limestone and is spoken of as such in the early reports. In Jefferson County it is nearly always present, but is of an impure, ferruginous nature. In northern Indiana, Armstrong, Clarion, Butler, and Elk counties it is probably only locally present and always thin.

Analyses of Johnstown limestone from Indiana, Jefferson, Armstrong, and Elk counties, Pa.

	No. 41.[a]	No. 42.[b]	No. 43.[b]	No. 44.[c]
Insoluble residue	13.790	32.790	15.060	[d] 33.900
Calcium carbonate ($CaCO_3$)	78.768	36.214	58.750	51.410
Magnesium carbonate ($MgCO_3$)	2.421	16.883	16.005	3.962
Ferrous carbonate ($FeCO_3$)	....	8.078	....	......
Alumina (Al_2O_3)	3.540	4.360	7.880	7.790
Ferric oxide (Fe_2O_3)		......		
Sulphur	.097	.056	.041	......
Phosphorus	.018	.056	.085	.033

	No. 45.[c]	No. 46.[e]	No. 47.[e]	No. 48.[f]
Insoluble residue	8.020	23.840	22.280	36.860
Calcium carbonate ($CaCO_3$)	82.393	53.750	64.160	50.357
Magnesium carbonate ($MgCO_3$)	1.891	9.989	1.838	2.467
Ferrous carbonate (Fe_2CO_3)	....	....	....	......
Alumina (Al_2O_3)	4.653	7.730	7.450	7.040
Ferric oxide (Fe_2O_3)				
Sulphur	....	....	....	......
Phosphorus	.300	.131	.305	.054

[a] Vol. H3, p. 190.
[b] Vol. H4, p. 221; analysis by A. S. McCreath.
[c] Vol. M3, p. 89.
[d] The ignited "insoluble residue" contains silica, 27.570 per cent; alumina, 4.800 per cent; ferric oxide, trace; lime, trace; magnesia, 0.245 per cent.
[e] Op. cit., p. 85.
[f] Op. cit., p. 92.

No. 41.—Tyhawk's quarry, 1 mile east of Black Lick Station, Indiana County (main bench): Compact; bluish gray; irregular fracture.

No. 42.—A. Gorman's quarry, 2 miles southwest of Smithport, Indiana County (upper portion): Hard and tough, with rough, irregular fracture and pearl-gray color; emits a strong argillaceous odor when breathed upon.

No. 43.—A. Gorman's quarry, 2 miles southwest of Smithport, Indiana County (lower portion): Hard and tough, with irregular fracture and bluish-gray color: emits a strong argillaceous odor when breathed upon; thickness in this quarry, 10 feet, with three thin clay partings.

No. 44.—N. B. Lane's property, 1 mile southeast of Brockwayville, Jefferson County: Hard and tough; argillaceous; more or less stained with iron oxide; color, generally dark gray.

No. 45.—John Iler's property, 1 mile northwest of Perrysville, Jefferson County: Rather hard and tough; fracture irregular, rough; dark bluish gray.

No. 46.—M. Davis's limestone, 1 mile southeast of Cochrans Mills, Armstrong County (outcrop specimen).

No. 47.—George S. Putney's limestone at Putneyville, Armstrong County: Rather coarse grained; hard and tough; bluish gray; irregularly stained with carbonaceous matter.

No. 48.—J. C. McAllister's farm, Horton township, Brandy Camp post-office, Elk County: Appearance sandy; rather course grained; very hard and tough; light bluish gray.

LOWER FREEPORT LIMESTONE.

In chemical composition, appearance, and other characteristics, this limestone is almost the exact counterpart of the Johnstown limestone. It is the most variable limestone of the Allegheny formation, being uncertain both in thickness and in quality. It is reported at many points, but probably is not persistent for long distances, and is not known to have anywhere a greater thickness than 5 feet.

Analyses of Lower Freeport limestone from Indiana, Jefferson, and Elk counties, Pa.

	No. 49.[a]	No. 50.[b]	No. 51.[c]	No. 52.[c]
Insoluble residue	5.502	8.210	8.400	2.070
Calcium carbonate ($CaCO_3$)	82.321	88.232	87.035	92.857
Magnesium carbonate ($MgCO_3$)	8.021	1.371	1.558	1.680
Alumina (Al_2O_3)	2.630	1.960	2.170	2.320
Ferric oxide (Fe_2O_3)				
Sulphur	.102	.048	--------	-------
Phosphorus	.017	.017	.057	.019

	No 53.[d]	No. 54.[e]	No. 55.[e]	No. 56.[e]
Insoluble residue	7.940	21.250	13.680	6.540
Calcium carbonate ($CaCO_3$)	82.000	57.321	69.357	81.875
Magnesium carbonate ($MgCO_3$)	6.311	8.854	9.308	7.189
Alumina (Al_2O_3)	2.736	7.940	4.835	2.750
Ferric oxide (Fe_2O_3)				
Phosphorus	.015	.038	.077	.066

[a] Vol. M2, p. 293.

[b] Vol. H4, p. 228; analysis by A. S. McCreath.

[c] Vol. M3, p. 88.

[d] Op. cit., p. 86.

[e] Op. cit., p. 91.

No. 49.—P. Brown's quarry, 4½ miles northeast of Blairsville, on Cambria and Indiana pike, Indiana County: Compact, brittle; bluish gray; irregular fracture.

No. 50.—S. Palmer's quarry, three-fourths of a mile northwest of Deckers Point, Indiana County: Irregularly seamed with white crystalline calcium carbonate; exceedingly brittle; rough irregular fracture and bluish-gray color.

No. 51.—N. B. Lane's property, 1 mile southeast of Brockwayville, Jefferson County: Fine grained, hard, and brittle; brownish gray.

No. 52.—Evans Round Top, one-half mile east of Corsica, Jefferson County: Fine grained, hard, and brittle; brownish gray.

No. 53.—Three miles northeast of Reimersburg, Toby Township, Clarion County: Very hard and tough; mottled and stained with ferric oxide; generally bluish gray.

No. 54.—T. Fox's farm, Horton Township, Mead Run, three-fourths mile north of Brockport, Elk County: Fine grained and brittle; fracture subconchoidal, bluish gray; known as "K limestone."

No. 55.—J. C. McAllister's farm, Horton Township, Elk County: Rather fine grained and brittle; fracture subconchoidal; bluish gray; known as "K limestone."

No. 56.—J. S. Chamberlain's farm, Horton Township, Brandy Camp Creek, 1¼ miles south of Brandy Camp post-office, Elk County: Rather fine grained and brittle; conchoidal fracture; light bluish gray.

UPPER FREEPORT LIMESTONE.

Although probably not persistent over large areas, this bed is of considerably greater importance than the preceding one. It is known to be present at a great number of points throughout the Allegheny Valley. Usually it is less than 6 feet, but occasionally swells to much greater thickness, as in the ravine of Fort Run, near Manorville, in Armstrong County, where, with its interstratified beds, it is nearly 28 feet thick and has been extensively quarried by A. J. Dull & Co. The Second Survey reports the following section at this place:

Section of Upper Freeport limestone near Manorville, Pa.[1]

	Ft.	In.
1. Limestone	1	3
2. Clay	0	8
3. Limestone, impure	1	0
4. Slate	2	2
5. Limestone	4	5
6. Clay slate and impure limestone	2	5
7. Limestone, dark colored	2	2
8. Slate and impure limestone	3	2
9. Limestone	2	10
10. Slate and clay	1	3
11. Limestone, called "glassy layer"	2	7
12. Limestone	4	0
Total	27	11

Benches numbered 5, 9, and 11 of this section have been analyzed, with the following results:

Analyses of Upper Freeport limestone from near Manorville, Pa.[a]

	No. 57.	No. 58.	No. 59.
Insoluble residue	4.830	7.310	4.520
Calcium carbonate ($CaCO_3$)	89.303	82.589	89.857
Magnesium carbonate ($MgCO_3$)	1.900	5.751	2.898
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.002	3.367	1.860
Phosphorus	.021	.063	.017

[a] Vol. H5, p. 257; analyses by McCreath.

No. 57.—Bench No. 5: Very compact and fine grained; dark pearl gray; conchoidal fracture.

No. 58.—Bench No. 9: Fine grained, hard, and tough; somewhat argillaceous; dark pearl gray; conchoidal fracture; small crystals of pyrite throughout the section.

No. 59.—Very compact and fine grained; slightly mottled with calcite; pearl gray; conchoidal fracture.

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[1] Vol. H5, p. 256.

Between Manorville and Kellys Station, in the vicinity of Logansport, the stone has been extensively quarried in the past for use as a flux, for which purpose it is well suited. It is also supposed to be a good limestone for use as a Portland-cement material.

The following section is reported from Mahaffey's quarry, Logansport:

Section of Upper Freeport limestone at Logansport, Pa.[1]

	Ft.	In.
1. Limestone	1	7
2. Limestone, impure	0	8
3. Limestone	2	4
4. Limestone, impure	0	10
5. Clay and slate	1	3
6. Limestone, impure	0	7
7. Limestone, "glassy layer"	5	6
Total	12	9

Analyses from benches 1, 4, and 7 of this section give the following percentages:

Analyses of Upper Freeport limestone from Logansport, Pa.[a]

	No. 60.	No. 61.	No. 62.
Insoluble residue	0.830	2.200	3.170
Calcium carbonate ($CaCO_3$)	96.453	93.214	93.571
Magnesium carbonate ($MgCO_3$)	1.445	2.065	1.324
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	.964	1.340	1.207
Phosphorus	.007	.004	.029

[a] Loc. cit.; analyses by McCreath.

No. 60.—Bench No. 1: Fine grained and brittle; dark pearl gray.

No. 61.—Bench No. 4: Fine grained and tough; dark pearl gray.

No. 62.—Bench No. 7: Very compact and fine grained; hard and tough; light pearl gray; conchoidal fracture.

It was formerly quarried for flux by the Kittanning Iron and Steel Manufacturing Company, but owing to the greater cost of quarrying than the Vanport, its use has been discontinued.

At several other points in Armstrong County workable thicknesses are reported by the Second Survey, and the following analyses have been made, showing the stone to be of fair quality for flux and cement.

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[1] Loc. cit.

Analyses of Upper Freeport limestone from Armstrong County, Pa.

	No. 63.[a]	No. 64.[a]	No. 65.[a]	No. 66[b].
Insoluble residue	1.850	1.920	5.030	9.520
Calcium carbonate ($CaCO_3$)	94.642	94.928	88.839	84.857
Magnesium carbonate ($MgCO_3$)	1.574	1.210	1.513	1.868
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	1.182	1.246	2.557	2.568
Phosphorus	.012	.018	.021	.024

[a] Vol. M3, p. 84. [b] Op. cit., p. 88.

No. 63.—S. Monroe's quarry, 2 miles southwest of Slate Lick: Fine grained; tough; dark pearl gray.

No. 64.—William Marshall's quarry, one-half mile east of Dayton: Fine grained; tough, mottled with calcite; dark gray; fracture conchoidal.

No. 66.—W. R. Hamilton's land near coal mine 1¼ miles north of Putneyville: Fine grained; tough; dark gray.

In Indiana County a thickness of 10 feet is reported at Groft Brothers' quarry near Chambersville, where it has been worked in the past; at Goods Mill on Little Mahoning Creek; at the Dick farm on Two Lick Creek, and possibly at several other localities. Usually, however, the thickness is considerably less than 10 feet.

Analyses of Upper Freeport limestone from Indiana County, Pa.

	No. 67.[a]	No. 68.[b]	No. 69.[c]	No. 70.[d]	No. 71.[d]
Insoluble residue	9.150	6.021	27.230	14.980	5.430
Calcium carbonate ($CaCO_3$)	84.407	84.125	54.768	72.264	89.821
Magnesium carbonate ($MgCO_3$)	2.800	5.198	8.627	6.493	1.801
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.120	3.220	6.930	4.190	1.700
Sulphur	.188	.073	.112	.068	.133
Phosphorus	.018	.014	.017	.029	.027

[a] Vol. H4, p. 254; analysis by McCreath.
[b] Vol. M2, p. 292.
[c] Vol. H4, p. 179; analysis by A. S. McCreath.
[d] Vol. M2, p. 292.

No. 67.—Groft Brothers' quarry, 1 mile east of Chambersville: Compact; brittle; dark bluish gray: irregular fracture.

No. 68.—Rev. S. Brown's quarry, 1½ miles southwest of Five Points: Compact; brittle; sparkles with calcite; bluish gray; subconchoidal fracture.

No. 69.—C. Livengood's quarry, 3 miles southeast of Blairsville: Compact; brittle; bluish gray; irregular fracture; sparkles with calcite; strong argillaceous odor; thickness, 3 feet or more.

No. 70.—D. R. Griffith's quarry, 1½ miles southeast of Homer: Compact; brittle; dark bluish gray; irregular fracture; strong argillaceous odor.

No. 71.—S. C. Hazlett's quarry, 2 miles north of Jacksonville: Compact; brittle; bluish gray; subconchoidal fracture.

In Jefferson County the limestone is occasionally reported, but its greatest known thickness is only 6 to 8 feet. It has been burned on a very limited scale for enriching the soil.

Analyses of Upper Freeport limestone from Jefferson County, Pa.[a]

	No. 72.	No. 73.	No. 74.	No. 75.	No. 76.
Insoluble residue	3.130	6.770	6.170	16.660	3.480
Calcium carbonate ($CaCO_3$)	91.875	88.928	89.107	48.571	90.000
Magnesium carbonate ($MgCO_3$)	2.421	1.589	1.611	23.762	2.860
Alumina (Al_2O_3)	1.312	1.740	2.140	7.250	1.285
Ferric oxide (Fe_2O_3)					
Phosphorus	.012	.023	.024	.032	.011

[a] Vol. M3, p. 88.

No. 72.—Property of D. Hopkins, 2 miles northeast of Frostburg: Very fine grained; brittle; mottled with calcite; pearl gray.

No. 73.—Property of A. Hoffman, 2 miles northeast of Woodville: Fine grained; brittle; mottled with calcite; pearl gray.

No. 74.—N. B. Lane's property, 1 mile southeast of Brockwayville: Fine grained; brittle: sparkles with calcite; generally pearl gray.

No. 75.—John Iler's property, 1 mile northwest of Perrysville (upper bench): Hard and tough; appearance sandy; fracture, irregular; color, light pearl gray.

No. 76.—John Iler's property, 1 mile northwest of Perrysville (lower bench): Rather fine grained: comparatively brittle; mottled with calcite; bluish gray.

In Elk and Clarion counties the limestone is not well known, but a general idea of its character may be gained from the following analyses:

Analyses of Upper Freeport limestone from Elk and Clarion counties, Pa.

	No. 77.[a]	No. 78.[b]	No. 79.[b]
Insoluble residue	12.290	5.320	1.800
Calcium carbonate ($CaCO_3$)	80.357	82.678	93.803
Magnesium carbonate ($MgCO_3$)	1.619	8.248	2.270
Alumina (Al_2O_3)	3.610	1.365	.765
Ferric oxide (Fe_2O_3)			
Phosphorus	.086	.022	.008

[a] Vol. M3, p. 91.

[b] Op. cit., p. 86.

No. 77.—J. S. Hyde's farm, Horton Township, 1 mile south of Brandy Camp post-office on Brandy Camp Creek, Elk County: Rather coarse grained; brittle; fracture irregular; light bluish gray.

No. 78.—Reichert's quarry, Perry Township, Clarion County: Rather fine grained; mottled with calcite; dark pearl gray.

No. 79.—New Athens, Madison Township, Clarion County: Rather fine grained; mottled and seamed with calcite; dark gray.

Summarizing, it may be said for the Upper Freeport limestone that, while of very irregular occurrence, it is frequently of workable thickness, and nearly always contains a fairly high percentage of lime, low percentage of magnesia, and low percentage of phosphorus, rendering the product suitable for Portland cement, flux, or fertilizer.

LIMESTONES OF THE CONEMAUGH FORMATION.

Between the Upper Freeport and Pittsburg coal beds no persistent bed of limestone is known, although the impure Ames bed is present at scattered points throughout the western portion of the valley, and the Pittsburg limestone occurs on a few of the hilltops in the southern part of Indiana and Armstrong counties and northern Westmoreland County. A specimen from A. H. Fulton's quarry, in the latter bed at West Lebanon, shows the following composition:

Analysis of Pittsburg limestone from Indiana County, Pa.[a]

	No. 80.
Insoluble residue	10.327
Calcium carbonate ($CaCO_3$)	82.768
Magnesium carbonate ($MgCO_3$)	2.875
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.830
Sulphur	.156
Phosphorus	.011

[a] Vol. M2, p. 289.

No. 80.—Generally compact and brittle; irregular fracture; bluish-gray color; seamed with bluish-black limestone.

Besides the beds mentioned, there are a number of more or less local beds known at scattered localities. A number of these have been analyzed, but the following instances are the only ones of which the exact stratigraphic position is known:

Analyses of local limestones in the Conemaugh formation, in Jefferson and Indiana counties, Pa.

	No. 81.[a]	No. 82.[a]	No. 83.[a]	No. 84.[b]
Insoluble residue	9.780	11.780	2.390	16.540
Calcium carbonate ($CaCO_3$)	75.357	77.143	92.500	65.892
Magnesium carbonate ($MgCO_3$)	9.330	4.691	2.497	9.686
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	4.230	3.790	1.530	5.710
Sulphur	....	....	....	.292
Phosphorus	.017	.073	.023	.016

[a] Vol. M3, p. 87. [b] Vol. M2, p. 366.

No. 81.—Property of James Smith, 2 miles northeast of Big Run, Jefferson County; about 125 to 150 feet above Upper Freeport coal: Fine grained, rather hard and tough; pearl gray.

No. 82.—Property of Jacob Smith, 2 miles north of Big Run, Jefferson County; about 150 to 175 feet above Upper Freeport coal: Fine grained; rather brittle; conchoidal fracture; irregularly seamed with calcite; dark bluish gray.

No. 83.—Property of James Smith, 2 miles northeast of Big Run, Jefferson County; about 200 to 225 feet above Upper Freeport coal: Rather coarse grained; brittle; bluish gray.

No. 84.—G. M. Doty's quarry, 5 miles northeast of Blairsville, Indiana County; about 120 feet below Pittsburg coal: Compact; brittle; bluish gray; irregular fracture; sparkles with calcite; emits strong argillaceous odor when breathed upon.

SEWICKLEY LIMESTONE.

Only in the extreme southern part of Indiana County are any rocks of the Monongahela or Dunkard formations present, and descriptions given under the heading "Monongahela Valley" will in general apply to limestones in these formations running across the divide into Allegheny Valley. The following is an analysis of the Sewickley limestone:

Analysis of Sewickley limestone from Indiana County, Pa.

	No 85.[a]
Insoluble residue	12.160
Calcium carbonate ($CaCO_3$)	79.821
Magnesium carbonate ($MgCO_3$)	3.601
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	3.020
Sulphur	.117
Phosphorus	.018

[a] Vol. H4, p. 159; analysis by A. S. McCreath.

No. 85.—Sewickley limestone from Robert Smith's quarry at Smiths Station, 2 miles northeast of Blairsville: Compact; brittle; sparkling with calcite; bluish gray; irregular fracture.

BENWOOD LIMESTONE.

The Benwood limestone is known in this region only on Elders Ridge and at one or two minor localities. On Elders Ridge it occurs in several layers separated by variable intervals of shale, the whole deposit being reported to be at least 25 feet thick. The limestone is reported on the J. and R. Smith farms, and outcrops on several rounded knobs in the vicinity, capped by a thin-bedded sandstone regarded as the division between the upper and lower parts of the Benwood limestone. Only fragmentary patches of the limestone are preserved, but what is left of it is smooth, light gray, and nonfossiliferous. It makes a strong lime, excellent for fertilizing purposes, and can be quarried at little expense.

BEAVER VALLEY.

Under this head will be discussed the few limestones of Beaver, Butler, and Lawrence counties.

MERCER LIMESTONES.

In the "Mercer group," which occupies the middle of the Pottsville formation and occurs at an interval ranging from 110 to 135 feet below the Vanport limestone, there are in Lawrence County two beds, known as the Upper and Lower Mercer limestones. Of these, the lower is the more persistent, being reported as almost universally present, but is always thin, with a maximum thickness of only 1 to 3 feet. On account of its great persistence it is valuable as a key rock in the region.

The horizon of the Upper Mercer limestone is 20 to 35 feet above the lower bed. Although not so commonly present, it is sometimes of slightly greater thickness, occasionally as much as 4 feet. Neither of the beds, however, can be considered as having economic value.

VANPORT LIMESTONE.

In Beaver Valley, as in the Allegheny Valley, the Vanport limestone is the most persistent, thickest, purest, and most massive limestone of the series. Its outcrop is shown by the blue line on Pl. V.

Beaver County.—Over southern Butler and the greater part of Beaver the Vanport limestone lies deep beneath the surface, but along Ohio River it occurs above water level. It has a thickness of 18 feet at Vanport, its type locality, 16 feet at Industry, 8 feet at Merrill, and 10 feet at Fallston, on Beaver River; elsewhere where observed it is less than 5 feet thick, usually less than 1 foot, and is sometimes entirely absent.

The following section is reported in Tygart's quarry, at Vanport:

Section of Vanport limestone at Vanport, Pa.[1]

	Feet.
Gray limestone	7
Shale	1
Gray limestone	5
Blue limestone	5
Total	18

The division of the limestone into the "gray" upper portion and the "blue" lower portion is usually well marked throughout the region. In the first two of the following analyses from Power's quarry, No. 86 is from the upper and No. 87 from the middle stratum.

Analyses of Vanport limestone from Power's quarry, near Vanport, Pa.[a]

	No. 86.	No. 87.	No. 88.	No. 89.
Insoluble residue	7.030	4.780	4.800	2.770
Calcium carbonate ($CaCO_3$)	88.464	91.607	91.089	93.482
Magnesium carbonate ($MgCO_3$)	1.445	1.566	1.587	1.544
Alumina (Al_2O_3) Ferric oxide (Fe_2O_3)	2.324	1.291	1.589	1.823
Sulphur	.097	.290	.047	.030
Phosphorus	.029	.030	.040	.047

[a] Vol. M2, p. 297.

No. 86.—Upper stratum: Compact, very brittle; irregular fracture; color, dull gray and reddish gray.

No. 87.—Middle stratum: Compact and tough; sparkling with calcite; spotted with pyrites; color, pearl gray and reddish gray.

No. 88.—Tygart's quarry, one-half mile below Vanport (lower bench): Hard and brittle; irregular fracture; sparkling with calcite; color, bluish-gray and reddish gray.

No. 89.—Severn's quarry, one-half mile below Vanport (upper bench): Exceedingly brittle; irregular fracture; color, generally reddish gray.

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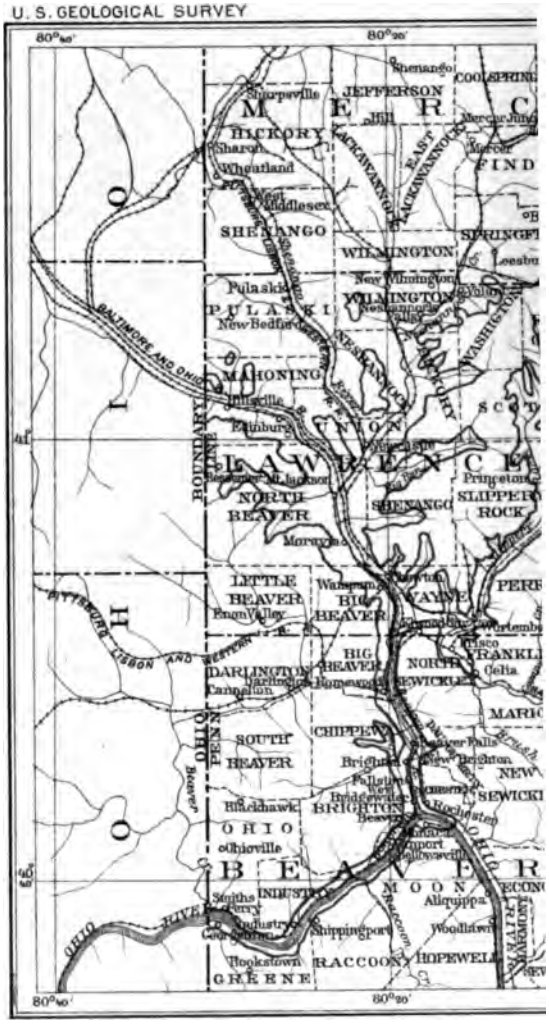
[1] Vol. Q, p. 61.

U. S. GEOLOGICAL SURVEY



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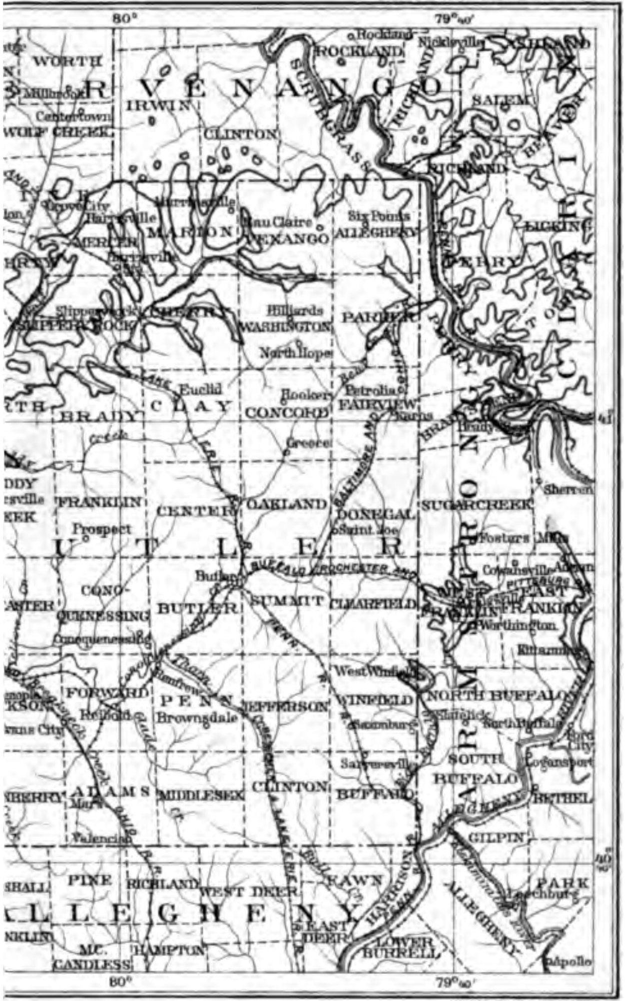

JULIUS BIEN & CO. LITH. N.Y.

BEAVER VALLEY AND VICINITY
F VANPORT LIMESTONE
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From a map published by the Second Geological Survey of Pennsylvania. 1893

The upper of the two beds is now burned extensively at Vanport for lime, which is of high quality and excellent as a flux for iron, for which purpose it was once shipped extensively to Pittsburg. The lower bed is usually rejected, but there is no known reason why this portion should not be suitable for the same purpose. At the time of the construction of the Erie and Pittsburg Canal the limestone was used in manufacturing natural cement for the locks.

Lawrence County.—In Lawrence County the Vanport limestone is very extensively present, underlying nearly two-thirds of the county. It often attains greater thickness than in Beaver County, frequently expanding to 15 feet, and sometimes as much as 20 feet, in thickness. The rock is extensively quarried for furnace flux at Newcastle, and at other points throughout the county. One of the Newcastle quarries is shown in Pl. VI. At Wampum, on Beaver River, the bed is 25 feet thick, and is quarried by the Crescent Portland Cement Company, which manufactures a cement of superior quality. The following analyses of stone from the upper, middle, and lower strata were made for the company:

Analyses of Vanport limestone from Wampum, Pa.[a]

	No. 90.	No. 91.	No. 92.
Lime (CaO)	[b]49.81	[c]50.16	[d]52.04
Magnesia (MgO)	[e].75	[f].42	[g].43
Silica (SiO_2)	4.50	4.14	2.31
Alumina (Al_2O_3)	.21	.21	.24
Ferric oxide (Fe_2O_3)	1.77	1.77	1.18
Manganous oxide (MnO)	.20	1.20	.22
Sulphur	.06	.20	.17
Phosphoric oxide (P_2O_5)	.07	.05	.04
Carbon dioxide (CO_2)	40.54	39.87	41.72
Water and organic matter	2.59	2.08	1.65

[a] Vol. Q2, p. 107; analysis by Robertson Brothers, of Pittsburg.
[b] Corresponds to approximately 87.90 per cent of $CaCO_3$.
[c] Corresponds to approximately 89.56 per cent of $CaCO_3$.
[d] Corresponds to approximately 92.98 per cent of $CaCO_3$.
[e] Corresponds to approximately 1.57 per cent of $MgCO_3$.
[f] Corresponds to approximately 0.88 per cent of $MgCO_3$.
[g] Corresponds to approximately 0.90 per cent of $MgCO_3$.

No. 90.—Upper portion.
No. 91.—Middle portion.
No. 92.—Lower portion.

Following are other analyses from Lawrence County:[1]

Analyses of Vanport limestone from Lawrence County, Pa.

	No. 93.	No. 94.	No. 95.	No. 96.
Insoluble residue	3.070	1.970	2.080	2.790
Calcium carbonate ($CaCO_3$)	93.340	95.768	94.785	94.214
Magnesium carbonate ($MgCO_3$)	1.460	1.097	1.369	1.732
Alumina (Al_2O_3)	1.563	.632	1.187	.805
Ferric oxide (Fe_2O_3)				
Sulphur	.123	.088	.123	.165
Phosphorus	.047	.017	.032	.020

No. 93.—Green's, Marquis's, and Johnson's quarries near Newcastle, Lawrence County: Compact, brittle; sparkling with calcite; bluish gray and pearl gray; irregular fracture.

No. 94.—McCord's quarry, 3 miles northwest of Mount Jackson, North Beaver Township, Lawrence County: Compact, brittle; sparkling with calcite: pearl gray; irregular fracture.

No. 95.—Moffit's quarry, 2 miles north of Croton, Lawrence County: Compact, brittle; sparkling with calcite; bluish gray and pearl gray: irregular fracture.

No. 96.—J. K. Shinn & Bros.' quarry near Wampum, Big Beaver Township, Lawrence County: Compact, brittle; sparkling with calcite; bluish gray.

LOWER FREEPORT LIMESTONE.

This limestone is known only occasionally in the region. On Elkhorn Run, in Beaver County, it has a thickness of 5 feet; at Beaver Falls, of 3 feet; in Bradys Run, of 5 to 8 feet; on Island Run of 5 feet; and in South Beaver Township, of 4 to 9 feet South Beaver is supposed to be the only township in which it has been burned. No analyses are known to have been made.

UPPER FREEPORT LIMESTONE.

Like the Lower Freeport limestone, this is irregularly present in the region. It sometimes appears only as nodules, is nearly always very thin, and is absent over large areas. In South Beaver Township, in Beaver County, and possibly in Lawrence County, it has been burned for lime. The following are the maximum thicknesses observed in Beaver County—5 feet at Monaca, 5 feet at a point 4 miles east of New Brighton, 4 feet on Raccoon Creek, 5 to 7 feet on Island Run, and 6 to 8 feet in South Beaver Township. In Lawrence County nothing is known of the limestone except that at several points it is said to range from 5 to 10 feet in thickness. No analyses are known.

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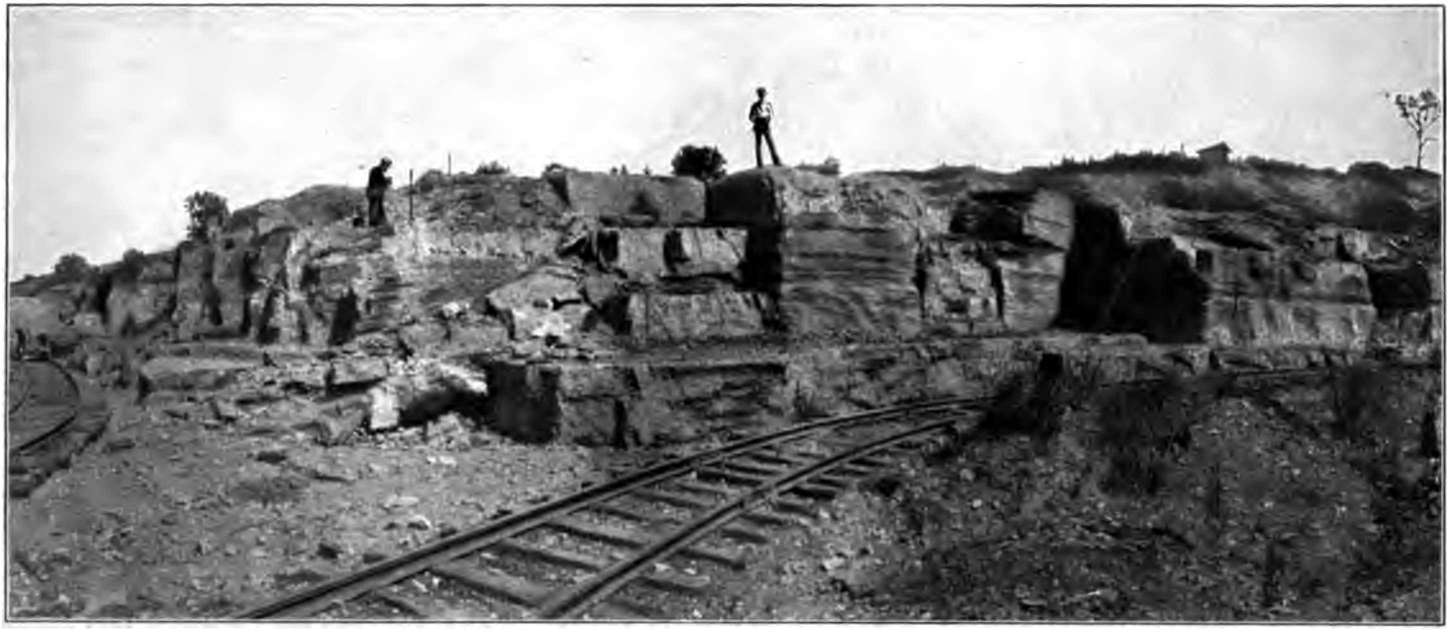
[1] Vol. M2, p. 287.



VANPORT LIMESTONE QUARRIES AT NEWCASTLE, PA.

(Photograph by M. R. Campbell.)

AMES LIMESTONE.

Several beds exist in the Conemaugh formation, but all are thin and of little or no value. The most persistent bed is the Ames limestone (Crinoidal), an impure and very fossiliferous bed averaging 230 feet below the Pittsburg coal. The rock is often entirely composed of crinoid stems and spines and other fossils closely packed together, forming a limestone unlike any other Carboniferous bed. This bed, on account of its dark-bluish-gray or greenish-gray color and peculiar fossiliferous appearance, is an excellent reference datum over wide areas. It is, however, of no economic value, being difficult to burn, and is seldom used even for fertilizer. In thickness the bed ranges up to about 6 feet, and is occasionally double.

ALLEGHENY MOUNTAINS.

The greater part of this region, including Clearfield, Cambria, and Somerset counties, is underlain by the Coal Measures, which have their eastern limit along the Allegheny Front, near the boundary of Blair and Bedford counties. East of this line the rocks have been eroded in places as deep as the Ordovician formations, while to the west all horizons are exposed from the Mauch Chunk to the base of the Monongahela formation. Only the region west of the main mountain crest will be considered in this report.

Of the limestones of this district very little is known, only small areas having been covered by the present survey. From what has been seen the limestones seem to be of comparatively little value. Following are the most important features in regard to the several beds:

LOYALHANNA LIMESTONE.

This bed is well shown along the Pennsylvania Railroad, wherever its horizon is exposed, at points from Blairsville to the Allegheny Front, above Altoona. It is easily identified by its peculiar weathering, which is well shown in Pl. VII, *A*. This is reproduced from a photograph taken at the "Viaduct," 1 mile east of Mineral Point, Cambria County. It is equally well shown at Allegrippus, just above the Horseshoe Curve (Pl. VII, *B*), and where Laurel Hill and Chestnut Ridge are cut by the Conemaugh west of Johnstown. Near the last-named place it is quarried extensively and crushed for railroad ballast.

JOHNSTOWN LIMESTONE.

This is the "cement bed" of the Pennsylvania reports, so called because it was once quarried for natural cement.[1] In this region it was earlier known as the Ferriferous limestone, being confused with the Vanport bed, which exists farther west. Allowance for this mistaken correlation must therefore be made when consulting the Cambria and Indiana counties reports. In Clearfield County the Johnstown limestone is almost or quite unknown, but throughout the greater part of Somerset and Cambria it is supposed to be nearly always present where its horizon outcrops, and in Somerset is a fairly good key rock. Usually it is a compact, brittle, bluish-gray limestone, with a probable maximum thickness of from 6 to 8 feet. Generally it contains high percentages of magnesia, iron, alumina, and silica, as shown by the following analyses from various points in Somerset County:

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[1] See analysis No. 40, p. 28.

Analyses of Johnstown limestone from Somerset County, Pa.

	No. 97.[a]	No. 98.[b]	No. 99.[a]	No. 100.[c]	No. 101.[d]
Insoluble residue	3.950	12.020	10.760	17.770	3.850
Calcium carbonate ($CaCO_3$)	92.298	54.821	69.264	52.940	90.544
Magnesium carbonate ($MgCO_3$)	1.483	23.088	13.773	16.060	2.134
Manganous carbonate ($MnCO_3$)	Trace.	Trace.	Trace.	....	....
Ferrous carbonate ($FeCO_3$)	1.167	8.492	4.739	5.800	1.503
Alumina (Al_2O_3)	.359	1.626	.403	4.440	.261
Sulphur	.097	.127	.106	.088	.464
Phosphorus	.018	.051	.047	.058	.013
Carbonaceous matter	.550	.980	.590	....	....

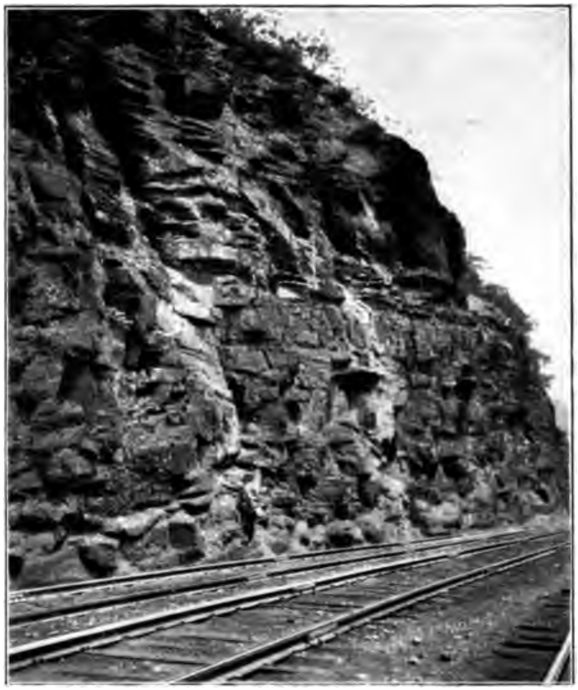
	No. 102.[e]	No. 103.[f]	No. 104.[g]	No. 105.[d]	No. 106.[h]
Insoluble residue	13.360	4.970	5.640	6.040	24.780
Calcium carbonate ($CaCO_3$)	50.160	79.478	88.139	86.778	63.969
Magnesium carbonate ($MgCO_3$)	18.494	10.222	1.854	2.908	4.244
Ferrous carbonate ($FeCO_3$)	11.600	3.693	1.798	2.972	4.393
Alumina (Al_2O_3)			.340		
Sulphur	.153	.168	.357	.166	.385
Phosphorus	.120	.034	.023	.137	.142

[a] Vol. H3, p. 231; analysis by A. S. McCreath.
[b] Loc. cit.; analysis by D. McCreath.
[c] Op. cit., p. 146.
[d] Vol. M2, p. 295; analysis by D. McCreath.
[e] Vol. H3, p. 134; analysis by D. McCreath
[f] Op. cit., p. 232; analysis by D. McCreath.
[g] Op. cit., p. 128; analysis by A. S. McCreath.
[h] Op. cit., p. 155; analysis by D. McCreath.

No. 97.—J. W. Beam's quarry at Jenner Crossroads (upper bench): Compact; brittle; fine grained; bluish gray.

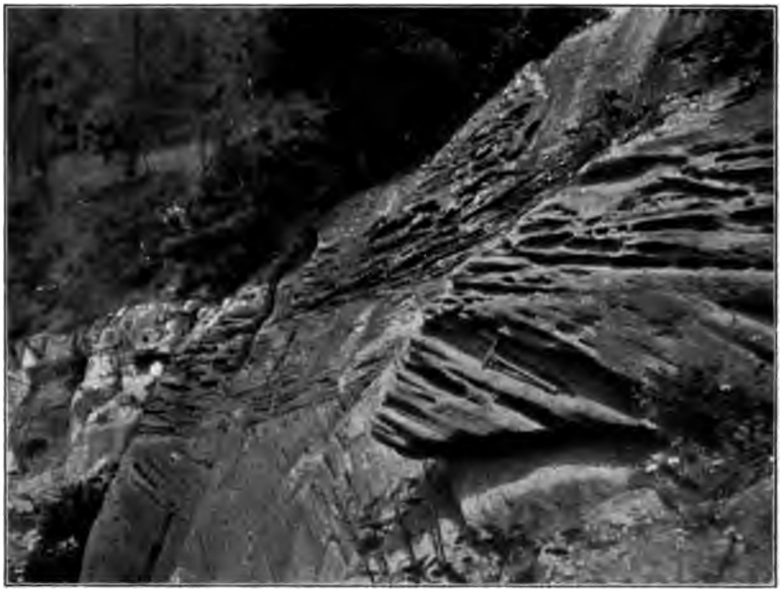
No. 98.—J. W. Beam's quarry at Jenner Crossroads (middle bench): Hard; brittle; bluish gray.

No. 99.—J. W. Beam's quarry at Jenner Crossroads (lower bench); Compact; brittle; bluish gray.



A. LOYALHANNA LIMESTONE RESTING ON SANDSTONE OF THE POCONO FORMATION, ALLEGRIPPUS, BLAIR COUNTY, PA.

(Photograph by Charles Batts.)



B. WEATHERED SURFACE OF THE LOYALHANNA LIMESTONE AT THE "VIADUCT," 1 MILE EAST OF MINERAL POINT, CAMBRIA COUNTY, PA.

(Photograph by M. R. Campbell.)

No. 100.—D. Rodger's quarry on Huskins Run, Shade Township: Hard; rather sandy; bluish gray.

No. 101.—Trevorrow's quarry, near Davidsville: Very brittle; fine grained; bluish gray.

No. 102.—J. Weaver's quarry, about three-fourths mile west of Scalp Level: Compact; bluish gray: much coated with iron oxide.

No. 103.—J. J. Pile's quarry, near Spiesville, on Quemahoning Creek: Compact; brittle; bluish gray.

No. 104.—Wilt's quarry, near Stoystown: Compact; fine grained; bluish gray.

No. 105.—Reitz's quarry, 1½ miles south-southeast of Friedenburg: Hard; compact; bluish gray.

No. 106.—Zimmerman's quarry, 3¼ miles southeast of Somerset: Compact; sandy; bluish gray; thickness over 6 feet.

Of these analyses it will be noticed that the first three are from different benches in the same quarry. The marked difference in composition illustrates the statement already made that several analyses from different portions of the bed should be made in order to obtain a correct idea of its quality.

FREEPORT LIMESTONES.

Neither of the Freeport beds is of importance in the region, although they are known to be frequently present, and at a few points have been opened by farmers. The greatest known thickness is at the east end of the west-bound tunnel of the Pennsylvania Railroad at Gallitzin, where the following section of the Upper Freeport limestone has been measured.

Section of Upper Freeport limestone at Gallitzin, Pa.

	Ft.	In.
Limestone	2	9
Shale	0	9
Limestone	2	4
Shale	0	3
Limestone	2	0
Shale	0	7
Limestone with shale partings	5	6
Shale	1	10
Limestone	2	8
Total	18	8

At a small opening 2 miles east of Ashville, in Cambria County, a bed supposed to be one of the Freeport limestones has been observed to be over 6 feet. An entire thickness of over 15 feet is reported at this point, but the truth of the statement can not be vouched for. On the land of Dan Caldwell, 1 mile northwest of Glen Hope, in Clearfield County, the Upper Freeport limestone has been burned in the past, and a sample from this locality showed the following composition:

Analysis of Upper Freeport limestone from near Glen Hope, Pa.[a]

	No. 107.
Insoluble residue	2.070
Calcium carbonate ($CaCO_3$)	93.810
Magnesium carbonate ($MgCO_3$)	1.710
Sulphur	.053
Phosphorus	.008

[a] Vol. H, p. 105.

At a few other points the beds have been burned locally for agricultural purposes.

LIMESTONES OF THE CONEMAUGH AND MONONGAHELA FORMATIONS.

Throughout the Conemaugh formation limestone beds are numerous, but are always thin, and can never be traced for long distances. In Cambria County the best-known exposures occur along the Pennsylvania Railroad cuts in the Wilmore basin between Summerhill and Munster, in which region beds up to 6 and 10 feet in thickness have been observed, but are never known to be persistent. The majority of these beds occur in an interval about 300 to 400 feet above the Upper Freeport coal.

Elk Lick limestone.—This bed of limestone attains considerable prominence in Somerset County. It occurs from 200 to 240 feet below the Pittsburg coal, and in its best development reaches a thickness of 12 feet. This limestone has not been studied by the present survey, but the Second Survey reports it as of a light-gray color, often tinged with buff. At a quarry three-fourths of a mile north of Ursina the bed is said to be 10 feet thick and to yield lime of superior quality. Several analyses have been made, which show the following compositions:

Analyses of Elk Lick limestone from Somerset County, Pa.

	No. 108.[a]	No. 109.[b]	No. 110.[b]
Insoluble residue	3.740	19.800	2.500
Calcium carbonate ($CaCO_3$)	90.803	55.589	89.522
Magnesium carbonate ($MgCO_3$)	2.738	14.224	5.327
Ferrous carbonate ($FeCO_3$)	1.986	6.835	1.812
Alumina		2.886	.224
Sulphur	.084	.185	.245
Phosphorus	.048	.032	.016

[a] Vol. H3, p. 259; analysis by D. McCreath.

[b] Vol. M2, p. 291 (D. McCreath).

No. 108.—Pittsburg Coal, Coke, and Iron Company's quarry, three-fourths of a mile north of Ursina: Exceedingly compact and fine grained; bluish gray; conchoidal fracture; thickness, 10 feet.

No. 109.—Elias Yoder's quarry, 1 mile west of Meyersdale: Hard; compact; bluish gray.

No. 110.—Peter G. Berkey's quarry, near Jenner Crossroads: Compact; bluish gray; conchoidal fracture.

Pittsburg, Redstone, and Sewickley limestones.—Of the Little Pittsburg, Redstone, and Sewickley limestones, which occur in a small area in southern Somerset County, little is known except from the following analyses:

Analyses of limestones from Somerset County, Pa.

	No. 111.[a]	No. 112.[b]	No. 113.[c]	No. 114.[d]
Insoluble residue	20.660	4.040	11.510	9.730
Calcium carbonate ($CaCO_3$)	64.706	86.625	74.808	69.160
Magnesium carbonate ($MgCO_3$)	2.156	6.152	6.734	15.555
Ferrous carbonate ($FeCO_3$)	4.274	1.825	5.282	3.935
Alumina (Al_2O_3)	1.700		1.548	1.366
Sulphur	2.431	.093	.052	.046
Phosphorus	.751	.023	.070	.017
Carbonaceous matter	2.602			

[a] Vol. H3, p. 75; analysis by A. S. McCreath.
[b] Vol. M2, p. 289.
[c] Vol. H3, p. 92; analysis by D. McCreath.
[d] Vol. M2, p. 287; analysis by D. McCreath.

No. 111.—Little Pittsburg limestone, from S. S. Flickinger's quarry, 2¼ miles north of Salisbury: Compact, very brittle; structure somewhat slaty: color, dark bluish gray; carries considerable coaly matter and much pyrite.

No. 112.—Redstone limestone, from M. J. Beechy's quarry, 2½ miles southwest of Salisbury: Minutely crystalline; pearl gray; conchoidal fracture.

No. 113.—Sewickley limestone, J. M. Hayes's quarry, 1 mile north of Salisbury: Hard: brittle; bluish gray.

No. 114.—Sewickley limestone, from Saylor Hill quarry, three-fourths of a mile west of Meyersdale: Compact; brittle; yellowish gray.

PAST AND PRESENT USES.

As a rule the Carboniferous limestones of Pennsylvania are not suited for building stone, but many of them, when burned, form lime of excellent quality for agricultural, building, and fluxing purposes. The most widespread use in the past has been as fertilizer, for which most of the beds are well adapted. The farmers have long since learned this, and the use of lime for this purpose is probably more prevalent in Pennsylvania than in any other State.[1] The proportion of farmers using lime on their land varies greatly in different counties, being generally, though not always, dependent on the amount of limestone available. The most extensive use is in Greene, Somerset, and Westmoreland counties, where over 75 per cent of the farmers use it to a greater or less extent. In Fayette, Cambria, Clarion, and Jefferson it is used by 50 to 75 per cent, in Indiana by 25 to 50 per cent, in Armstrong by a few farmers only, and on the soils of Washington, Beaver, Lawrence, Butler, Allegheny, and Clearfield counties it is rarely used.

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[1] The use of lime on Pennsylvania soils is discussed at length by William Frear in Bull. Pa. Dept. Agric. No. 61, 1900, 170 pages.

A number of beds of limestone are worked for railroad ballast, especially the Loyalhanna and Vanport. For this and other purposes the Vanport limestone is extensively quarried at West Winfield, in eastern Butler County. At this place it is mined by A. G. Morris and "used for ballast, concrete work, artificial stone, fluxing, and chemical purposes, and is burned into lime." The Loyalhanna limestone is used for paving blocks and is crushed for ballast on Youghiogheny River above Connellsville, on Loyalhanna Creek above Latrobe, and on Conemaugh River below Johnstown.

In the past a number of the beds, notably the Vanport, Johnstown, and Benwood, have been used in making natural cement, which, among other purposes, was used in the construction of locks on the Erie and Pittsburg Canal and on Monongahela River.

Perhaps the most important use of limestone at present is in the manufacture of Portland cement. For this cement a limestone of high grade is necessary. The percentage of magnesium carbonate, especially, must be less than 5 per cent, the amount of calcium carbonate should be at least 75 per cent, and the ratio of silica to alumina plus iron should be as 5 is to 2. However, as this ratio can usually be obtained by mixing with other raw materials, it is not necessary that the stone should possess a composition strictly within these limits. Suitable limestones are not abundant in western Pennsylvania, but the Vanport is almost universally low enough in magnesia, and the Upper Freeport usually so. The majority of the beds show in some places a suitable composition, but at other localities, and often in the same quarry, are entirely unsuitable. On account of the extensive outcrop of the Vanport limestone there is in this region a wide field for the founding of new Portland-cement factories. At present the only plant in this region is that of the Crescent Portland Cement Company at Wampum. In eastern Ohio there are a few plants.

SUMMARY.

The foregoing pages give, in brief, the extent of present knowledge of the limestones of western Pennsylvania. The economic importance of the beds may be summarized as follows:

The limestones of the Pocono formation are probably of no value except for railroad ballast and paving blocks.

The Greenbrier makes an excellent lime for fertilizer, and it has been used to some extent as a flux.

The Mercer limestones are usually too thin to be of any value.

The Vanport limestone is the purest bed known in western Pennsylvania. Almost without exception it contains a fairly high percentage of lime, low percentages of magnesia, phosphorus, and silica, and probably may be depended upon as an excellent source of supply in Portland-cement manufacture. It also furnishes the best stone for nearly all purposes for which limestone is used.

The Johnstown limestone is of some value for burning into natural cement, but is wholly unsuited for Portland cement, containing as it does high percentages of magnesia.

The Lower Freeport limestone is a thin bed, variable both in occurrence and in amount of impurities, and generally can not be depended upon for economic purposes.

The Upper Freeport limestone is occasionally of workable thickness and usually of considerable purity. The majority of the analyses show a small percentage of magnesia, with about the right proportions of iron, alumina, and silica for cement-making limestone, for which purpose it is available in certain regions.

The Ames limestone is of no economic importance.

The Elk Lick limestone may be of some value in Somerset County, but little is known of it.

The Pittsburg limestone seems to be of a moderate degree of purity, but is usually thin and can probably be worked only locally.

The Redstone limestone has in the past been considerably used for fluxing purposes, but it appears to contain too much magnesia to be of value for Portland cement.

The Sewickley limestone is shown by the only known analysis to be of considerable purity and probably suitable for cement manufacture.

The Benwood limestone can be used for various purposes, but its analyses show that its quality is extremely variable.

The Waynesburg limestone is a bed of good quality, which makes a strong lime. Its suitability for cement has not as yet been tested.

The Upper Washington limestone is reported to make lime of good quality, and if it maintains the approximate composition shown by the only known analysis, may be expected to be available for cement.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 249.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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DEPARTMENT OF THE INTERIOR

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CHARLES D. WALCOTT, DIRECTOR

THE PETROLEUM FIELDS OF THE PACIFIC COAST OF ALASKA

WITH AN ACCOUNT OF THE BERING RIVER COAL DEPOSITS

BY

GEORGE C. MARTIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 5, 1904.

SIR: I beg to submit herewith the manuscript and illustrations of a report entitled "The Petroleum Fields of the Pacific Coast of Alaska, With an Account of the Bering River Coal Deposits," by Mr. George C. Martin, assistant geologist, and to recommend its publication as a bulletin.

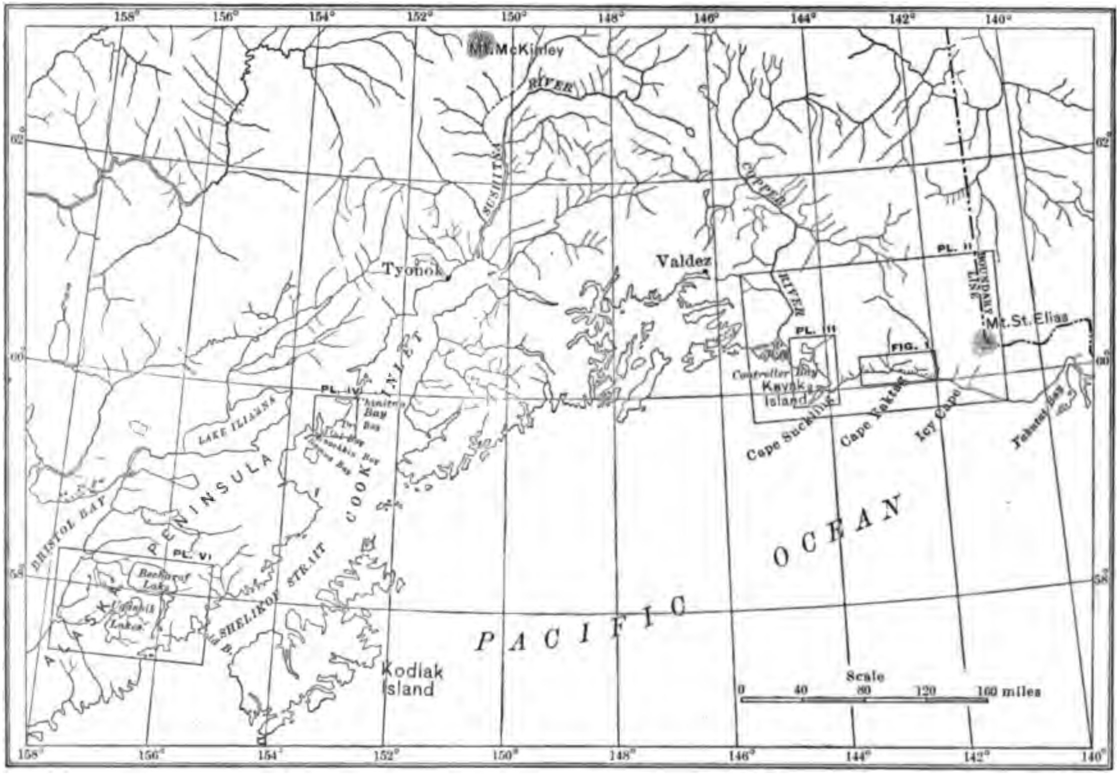
This report contains the result of a hasty examination of the structural and economic geology of the localities where indications of petroleum have been found. Though only a few wells have been drilled and it is too soon to predict an important future for the region as a petroleum producer, Mr. Martin's studies have shown that there is ample justification for further prospecting and that the region may yet be an important source of illuminating oil. In this connection it is of interest to note that the Bering River coal is the best that has yet been found on the Pacific coast of North America.

These coal and petroleum fields have been deemed of sufficient importance to justify the further investigation already begun, and it is hoped that this, together with the commercial development, will soon permit of more definite statements regarding the economic importance of this field.

Very respectfully,

ALFRED H. BROOKS,
Geologist in Charge Division Alaskan Mineral Resources.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



OUTLINE MAP, SHOWING GENERAL LOCATION OF OIL FIELDS AND AREAS OF LARGE-SCALE MAPS.

THE PETROLEUM FIELDS OF THE PACIFIC COAST OF ALASKA, WITH AN ACCOUNT OF THE BERING RIVER COAL DEPOSITS.[a]

By George C. Martin.

INTRODUCTION.

For several years indications of petroleum have been observed at Cape Yaktag,[b] near Controller Bay, on the western shore of Cook Inlet, and at many points on the Alaska Peninsula; and high-grade coal has been known on Bering River. A large amount of capital has been invested in these fields, several wells having been drilled, many coal openings made, and other improvements undertaken and projected. The verbal and newspaper reports from the region have been varied and conflicting, while such statements as have been published by geologists have not been based upon their own observations. Some of the petroleum and coal properties have been carefully examined by geologists or mining engineers in the interests of the owners, but their reports have not been made public.

In response to a general demand for information a reconnaissance of the petroleum and coal fields in the vicinity of Controller Bay and Bering River and of the petroleum fields on the west shore of Cook Inlet and at Cold Bay was made by the writer during the months of June, July, and August, 1903, and during the summer of 1904. The following is a statement of the results of the former investigation supplemented by some of the more important results of the latter.

These fields, though widely separated, are all on the southern coast of Alaska and, except the Bering River coal fields, on tide water. The Controller Bay petroleum fields are near the mouth of Copper River, and the Cape Yaktag fields are 75 miles farther east. The Cook Inlet fields are about 320 miles west of Controller Bay, in the middle part of the western shore of Cook Inlet, and the Cold Bay field is about 160 miles to the southwest on the southern coast of the Alaska Peninsula. The Bering River coal fields are from 20 to 40 miles from the coast, in the valley of Bering River, which flows into Controller Bay. (See Pl. I.)

---

[a] See preliminary report, Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382.

[b] Commonly spelled Yakatag or Yakataga.

All these regions may be reached directly by steamer from Seattle, except the Cape Yaktag field, where there is no regular steamer landing. Controller Bay is from seven to nine days' sail from Seattle, Cook Inlet is about three days farther, while Cold Bay is two days beyond this. In order to reach the Cape Yaktag fields it is sometimes necessary to secure a small boat for the trip, or to walk from Controller Bay.

The earliest reference in print to the occurrence of petroleum in Alaska was by Ivan Petroff,[a] who, in 1882, said: "In the vicinity of Katmai both coal and petroleum have been found, but not abundant in quantity or excelling in quality."

Dr. W. H. Dall[b] in 1896 referred to the occurrence of petroleum on the portage from Katmai. "The petroleum is said to be a dark lubricating oil which floats on the surface of ponds and lakes."

In 1898 Mr. F. H. Oliphant published a brief statement of the indications of petroleum[c] in the Cape Yaktag, Controller Bay, and Cook Inlet regions. The character of the oil is described and a few geologic notes are given, and in 1899[d] these notes were republished.

Mr. G. H. Eldridge published in 1899 some observations on the Bering coal field and on the Controller Bay and Cape Yaktag oil fields,[e] and in 1900 Mr. J. E. Spurr[f] called attention to the occurrence of coal and petroleum in the vicinity of Controller and Icy bays and published some facts, furnished by Mr. F. H. Shepherd, concerning the geology of the region and the composition of the coal.

A brief statement of the progress of development was made by Mr. F. H. Oliphant[g] in 1900, and republished[h] in 1901.

The same year Mr. John Kirsopp, jr.,[i] published an account of the petroleum and coal in the Controller Bay and Bering River fields.

---

[a] Alaska, its population, industries, and resources: Tenth Census of the United States, vol. 8, p. 87.

[b] Coal and lignite of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, p. 799.

[c] Petroleum, in Mineral Resources U. S. for 1897: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1898, p 110.

[d] Petroleum, in Mineral Resources U. S. for 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1899, p. 123.

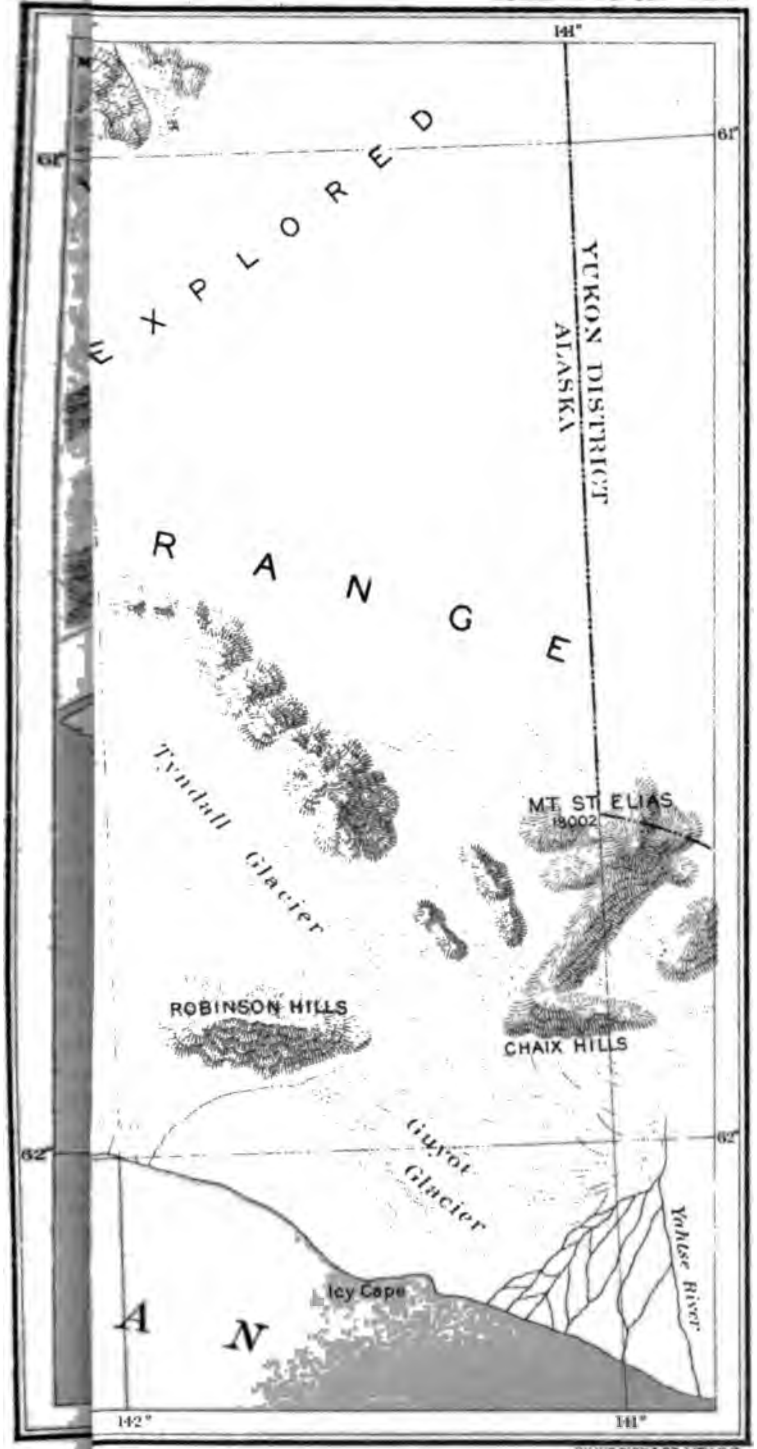
[e] The coast from Lynn Canal to Prince William Sound: In Maps and Descriptions of Routes of Exploration in Alaska in 1898; a special publication of the U. S. Geol. Survey, 1899, pp. 103–104.

[f] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 263–264.

[g] Petroleum, in Mineral Resources U. S. for 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 6 (continued), 1901, p. 167.

[h] Petroleum: Mineral Resources U. S. for 1900, U. S. Geol. Survey, 1901, p. 587.

[i] The coal fields of Cook Inlet, Alaska, U. S. A., and the Pacific coast: Trans. Inst. *Min. Eng., vol. 21, pp. 536–538, 559.*



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In 1901 Mr. F. C. Schrader and Dr. Arthur C. Spencer[a] published an analysis of a sample of coal furnished them from Bering River, and a description of two samples of petroleum from the Controller Bay region. The facts in regard to the coal were summarized in 1902 by Mr. Alfred H. Brooks,[b] and he also made reference to the reported existence of petroleum between Yakutat and Controller bays, and on the west side of Cook Inlet. A statement of the operations in the Controller Bay and Cook Inlet petroleum fields[c] was made by Mr. F. H. Oliphant in 1902.

An account of the occurrence of petroleum[d] at Cold Bay, with notes on the geology of the region, was published anonymously in 1903, and Mr. F. H. Oliphant also described in considerable detail the progress of operations in the Controller Bay oil fields,[e] with references to the Cook Inlet fields. An abstract[f] of the following report was published in April, 1904, and the information therein contained was used by Mr. F. H. Oliphant[g] as the basis for his statement of the progress of operations in 1903.

CONTROLLER BAY REGION.

GEOGRAPHY.

Controller Bay, an indentation of the coast about 100 miles west of Mount St. Elias, is sheltered on the southeast by Cape Suckling and on the southwest by a group of islands of which the largest is Kayak (Pl. II). The area here to be discussed includes the shores of Controller Bay and the adjacent region, with an irregular group of low peaks having no uniform elevation or trend, which form the foothills of the Chugach Mountains to the north. These foothills are highest near the mountains and fall away irregularly toward the sea, where few points are more than 2,000 feet high. The eastern shore of Controller Bay and of Bering River is low and almost flat.

Bering River, with its tributaries, drains the central part of this region and flows through a lake of the same name, which is about 10 miles from the sea. Above the lake it receives Canyon Creek and Stillwater Creek, the latter draining Lake Kushtaka. Shepherd

---

[a] Geology and Mineral Resources of a Portion of the Copper River District; a special publication of the U. S. Geol. Survey, 1901, pp. 91–92.

[b] Brooks, A. H., Coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 542, 549, 551, and 571.

[c] The production of petroleum in 1901: "Extract from" Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 208. (Not in bound volume.)

[d] The Cold Bay oil field: Eng. and Min. Jour., vol. 76, pp. 618–619.

[e] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, pp. 582–584 (pp. 207–209 of separate).

[f] Petroleum fields of Alaska and the Bering River coal fields: Bull. U. S. Geol. Survey No. 225, 1904, pp. 365–382.

[g] The production of petroleum in 1903: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, pp. 690–692 (pp. 179–181 of separate).

Creek enters Bering Lake from the north at its northeast corner, while Nitchawak River enters Bering River from the east between the lower end of the lake and Controller Bay. Katalla River and a number of small streams drain the peninsula between the lake and Controller Bay. The region northwest of the valley of Katalla River drains into the Copper River delta. (See Pl. III.)

Most of the lowlands about Controller Bay are covered with a dense forest. Spruce and hemlock predominate among the larger trees and are of good size and fair quality. This heavy growth extends up the hillsides to an elevation of about 1,000 feet, where it gives way to less dense timber of the same species and grades into a zone in which scrub alders are far in excess of the other trees. In the lower part of the valley of Shepherd Creek and in the valley of Katalla River there are meadows covered with a luxuriant growth of grass.

The various companies interested in the development of this region have built trails from cabin to cabin, and land travel is confined to these and to a good wagon road which has been built for about 10 miles west from the mouth of Bering River to the wells 4 miles east of Katalla, with branches up the valleys of Chilkat, Burls, Mary, and Redwood creeks.

There are two short tram roads from the mouth of Redwood Creek and from the head of Katalla Slough to neighboring oil wells, and one tram road from the banks of Shepherd Creek to a neighboring coal opening. The network of rivers, however, makes it very easy to get about in small boats, so almost all travel is done in that way.

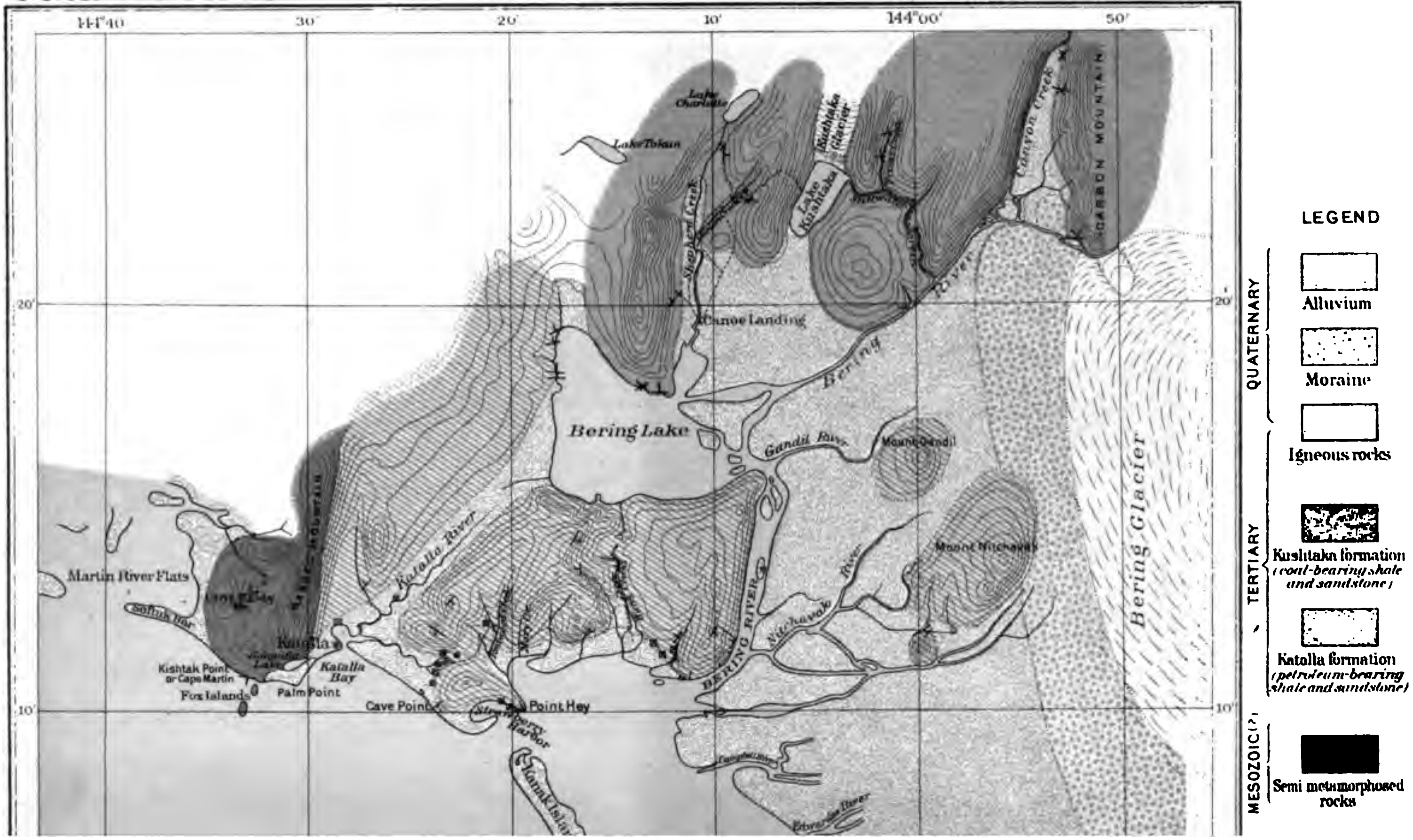
The most important settlements are Kayak, on Wingham Island, which is the steamer landing for the entire region, and the town of Katalla, at the mouth of Katalla River. There are no other settlements except the camps of the various operating companies and several small Indian villages. Kayak and Katalla are post-offices.

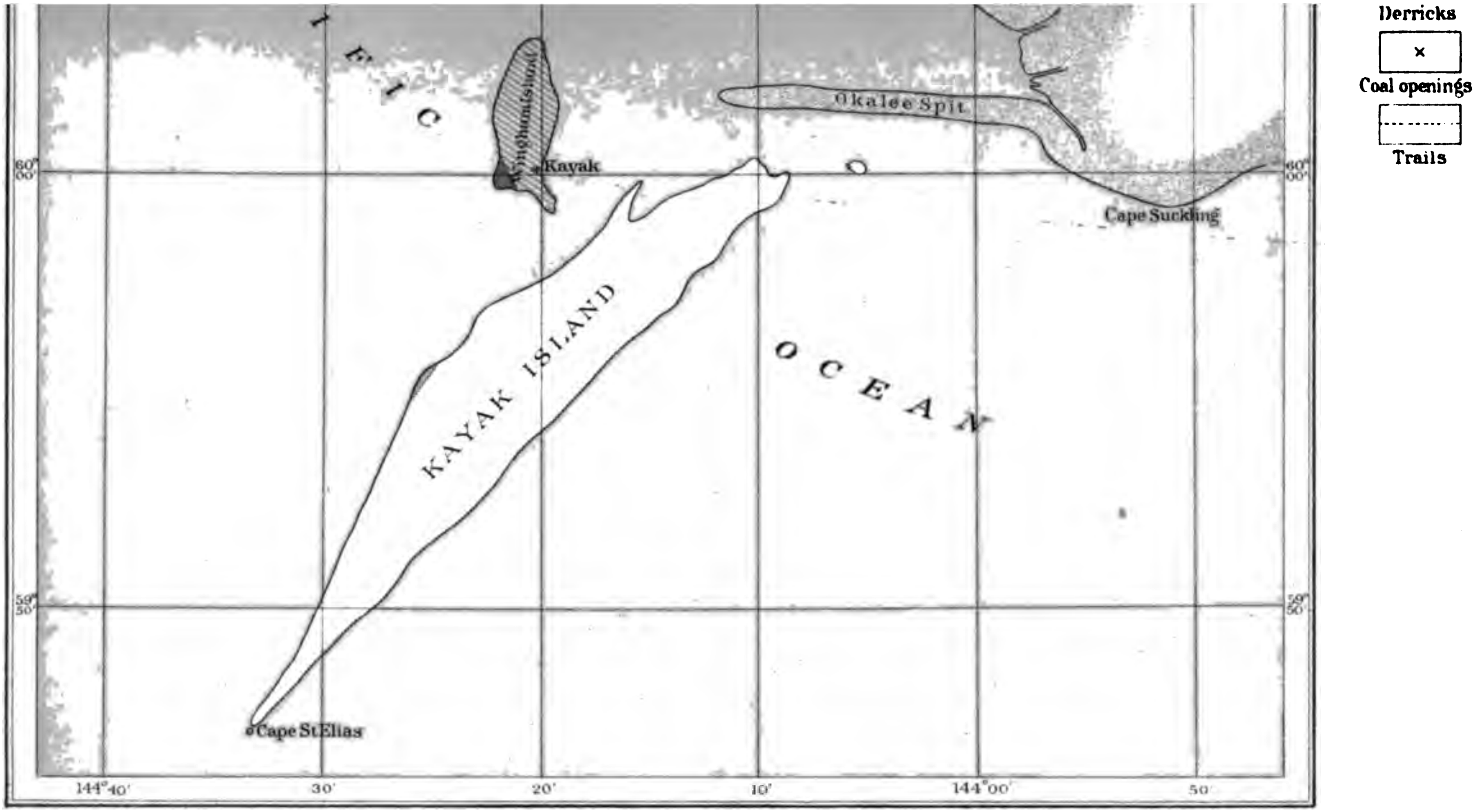
GEOLOGY.

The rocks include a complex series of semimetamorphosed beds, some oil-bearing shales, a succession of coal measures, a series of Miocene sandstones, conglomerates, and shales, a few igneous rocks, and a large area of alluvial and glacial deposits. The map (Pl. III) is based on such facts as could be gathered during a hasty reconnaissance.

SEMIMETAMORPHOSED ROCKS.

Under this heading is placed a succession of slightly metamorphosed sandstone, limestone, and shale which vary in color from dark gray to dull shades of red and green, frequently with a mottled


144°40'
30'
20'
10'
144°00'
50'
20'
10'
Lake Charlotte
Lake Tokun
Shepherd Creek
Kushtaka Glacier
Lake Kushtaka
Canyon Creek
CARBON MOUNTAIN
Canoe Landing
Bering River
Bering Lake
Gandil River
Mount Gandil
Mount Nichawak
Nichawak River
BERING RIVER
Bering Glacier
Katalla River
Martin River Flats
Softuk Bar
Katalla
Kishtak Point or Cape Martin
Fox Islands
Palm Point
Katalla Bay
Cave Point
Point Hey
Strawberry Harbor
Kanak Island
Edwardes River
LEGEND
QUATERNARY
Alluvium
Moraine
Igneous rocks
TERTIARY
Kushtaka formation (coal-bearing shale and sandstone)
Katalla formation (petroleum-bearing shale and sandstone)
MESOZOIC(?)
Semi metamorphosed rocks



MAP OF THE CONTROLLER BAY REGION

COMPILED FROM THE CONTROLLER BAY CHART OF THE COAST AND GEODETIC SURVEY, FROM MAP BY J. L. McPHERSON AND FROM PLANE-TABLE SURVEY BY G. C. MARTIN

1904

Geologic reconnaissance by G.C.Martin

Scale

0 1 2 4 6 8 10 miles

Sketch contours, interval approximately 250 feet

appearance. The degree of metamorphism is slight, the alteration being apparently the effect of crushing and infiltration. None of the minerals show the effect of extensive recrystallization.

The series is best exposed west of Katalla (see map, Pl. III) and along the neighboring shore of the Pacific, where the beds are steeply folded, dipping almost 90°, and are also somewhat crumpled. There are excellent exposures, too, on the Fox Islands, which are made up of this same series, and it was apparently again observed at the extreme southwest point of Wingham Island. Rocks of the same general appearance were also seen about 3½ miles north of Kishtak Point, in Lone Baldy Mountain, and in the valley north of that region. At the latter place petroleum was noticed in the joints. The high ranges to the north and northeast of this point are apparently composed of this formation, or of one very similar in character dipping at a high angle.

There is no evidence of the age of these rocks, or of their relation to the others to be described, except that they are apparently older than all the latter. It is possible that they represent part of the Orca or Valdes series of the Copper River region.

KATALLA FORMATION.

The Katalla formation is a series of dark argillaceous and carbonaceous shales, with occasional bands of sandstone, limestone, conglomerate, and volcanic ash. It is the series through which the petroleum of the region reaches the surface. The formation is typically exposed in the region to the northeast of Katalla, along the banks of Katalla River, and in the range of hills to the southeast. From this point it extends eastward, occupying the whole of the peninsula between Bering Lake and Controller Bay and outcropping in most of the hills south and east of Bering River. Good exposures were seen on the west shore of Bering Lake, and it is possible that some of the shales and sandstones of Kayak and Wingham islands represent the same formation. No estimate could be made of the thickness of the formation because of the complicated structure in all the districts where it is exposed.

The few fossils that have been obtained indicate that the Katalla formation is of Tertiary age. Several specimens of a crab and fragments of a gastropod were collected on the west shore of Bering Lake, and fragments of a pelecypod were seen at the mouth of Bering River, and a fossiliferous limestone concretion with many fragmentary pelecypods was collected in the bed of Chilkat Creek. These were submitted for determination to Dr. T. W. Stanton, who reports as follows: "The very small lots from the neighborhood of Bering Lake and Controller Bay are probably of Tertiary age." The following lists give the preliminary determinations of fossils from each locality.

2938. West end of Bering Lake, in concretions. Several specimens of a crab apparently belonging to the group Catometopa and related to the modern genus *Pilumnoplex* of the family Goniopladdæ. The Catometopa range back only to the Eocene according to Zittel. It seems probable, therefore, that these specimens are not older than Tertiary.

A fragment labeled "Camp of June 27 to 29, west end of Bering Lake," shows an imprint of a small costate gastropod not well enough preserved for identification.

2939. North end of Bering Lake, Alaska. Fragment of a gastropod that may be a *Turbo* or a related form. Small indeterminate bivalve, possibly a venerid.

2940. Mouth of Bering River, Controller Bay. Fragments of an undetermined bivalve.

2946. Chilkat Creek near Controller Bay. Fossiliferous limestone nodule with many fragmentary bivalves. Nothing determinable.

Point Hey, Controller Bay,[a] *Phacoides* (?) sp., *Callista* (?) sp., *Conus* sp., *Fusus* sp. A (medium), *Fusus* 2 sp. (small), *Turritella* sp., *Dentalium* sp. "Poor material, but the *Conus*, *Fusus*, and *Dentalium* look like Eocene forms."

Between Point Hey and Strawberry Point.[a] *Astrodapis* (?) sp., *Semete* (?) sp., *Dentalium* sp.

The paleontologic evidence concerning the position of the formation is therefore rather indefinite, but indicates that the age is certainly Tertiary and probably Eocene. There is no stratigraphic evidence on this question, for the exact age of neither of the adjacent formations has been determined with certainty. While the Katalla shales are evidently younger than the semimetamorphosed rocks, which may be the equivalent of the Paleozoic or Mesozoic Orca or Valdes formation, they are probably older than the Kushtaka coal measures, which are doubtful, but probably of Oligocene age.

KUSHTAKA FORMATION.

This name is here proposed for a coal-bearing series of strata, exposed in the valley of Bering River and its tributaries and on the shores of Lake Kushtaka, and consisting of an unknown thickness (at least many hundred and probably several thousand feet) of shale, arkosic sandstone, and coal seams. No detailed section of the formation has been found. Its areal extent, so far as now known, has been indicated in a preceding paragraph and is shown on the accompanying map (Pl. III). Its lower boundary may be taken at the base of the lowest coal in this region or at the first mappable stratigraphic break below that. Its upper limit may be taken at the top of the highest coal or at the next succeeding mappable stratigraphic break.

The formation is distinguished from the Katalla formation, which lies in an adjacent belt to the south of it, by the presence of coal seams, the predominance of sandstone over shale, and the coarseness of the sediments. It evidently adjoins on the north a belt of crystalline formations, of which numerous fragments have been transported into this region by streams and glaciers. The stratigraphic relation to the formations existing in the adjacent areas is not known, except that the general structure of the region is such as to indicate that it overlies the Katalla formation, which probably occupies a low horizon in the Tertiary.

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[a] Determined by Dr. W. H. Dall and Dr. Ralph Arnold.

The formation has yielded the following fossils (as determined by Dr. F. H. Knowlton): *Salix* sp. cf. *S. varians*, *Corylus macquarrii*, *Betula prisca*, and *Betula grandifolia*. All of these occur also at Port Graham in the Kenai formation, and are representative of the so-called Arctic Miocene or Oligocene. Poorly preserved fragments, which probably represent species of *Zizyphus* and *Laurus* were also found.

MIOCENE ROCKS.

The rocks exposed on the north shore of Kayak Island consist of beds of conglomerate, sandstone, and shale, with a marine fauna in which Dr. W. H. Dall and Dr. Ralph Arnold have identified the following species: *Leda* sp. A. (smooth), *Yoldia* aff. *scissurata* Dall, *Yoldia* aff. *thraciaformis* Dall, *Macoma* cf. *calcarea* Gmel., *Callista* sp., *Natica* sp., *Chrysodomus* sp. A., *Chrysodomus* sp. B., *Rostellites* cf. *indurata* Conrad. They are of the opinion that this fauna is upper Oligocene or lower Miocene, and is the equivalent of the marine faunas at Unga and Cape Yaktag.

IGNEOUS ROCKS.

Several igneous masses were seen on the west shore of Bering River near its mouth, and include dikes of a light-colored, fine-grained rock, tentatively determined under the microscope to be a micro-granite. About one-half mile above this point and just below the Chilkat Indian village are numerous exposures of a fine-grained, dark-green, igneous rock, which upon examination proves to be a chloritized tuff.

A massive, light-colored, medium-grained rock is exposed in the north bank of Bering River at the south end of Carbon Mountain, and the island in the river at this point is perhaps of the same composition. It is possibly of igneous origin and may have furnished the heat that produced the coke occurring in the vicinity. Specimens of this massive rock were collected but were lost in shipment, and no determination of either its name or its general character can be made. Several large masses of a basic glassy rock have broken up through the Miocene rocks on the north shore of Kayak Island.

The extreme southern end of Kayak Island, known as Cape St. Elias, rises in a high peak, having the appearance of a volcanic plug. The rock is of light color, has a columnar jointing, and is somewhat exfoliated and has been identified microscopically as a trachyte.

PLEISTOCENE AND RECENT DEPOSITS.

At the southern end of Wingham Island are good exposures of horizontal or gently dipping unconsolidated sand, clays, and gravels. These strata rest unconformably upon the upturned edges of the shales, which make up the larger part of the island. They are fossiliferous, containing *Ostrea* and a variety of other pelecypods and gastropods, which are surely not older than Pliocene. It is possible, and from the structural relations of these beds as compared with the other Tertiary and Quaternary deposits of the coast of Alaska, it seems probable that these beds are, indeed, very late Tertiary or post-Tertiary. They are exposed at an elevation of from 10 to 30 feet, and possibly date from the most recent elevation of the coast. Gravels which are accompanied by finer deposits and carry no fossils are exposed in a similar position along the bluffs near and to the west of Fox Islands, and probably also represent the most recent elevation.

The eastern shore of Bering River and Controller Bay, from a point slightly below the mouth of Stillwater Creek to the ocean, is a flat plain of sand and mud, constantly growing by the addition of sediment which the streams from the southwestern margin of the Bering Glacier carry and deposit along their courses and at their mouths. Mount Nitchawak, Mount Campbell, Mount Gandil, and other peaks rise like islands from this plain, and it seems certain that a very short time ago they were islands in an older extension of Controller Bay, then as now being filled by the sediment of these glacial streams. This younger fluviatile Quaternary formation extends along the northern bank of Bering River from a point about 3 miles below the mouth of Stillwater Creek to Bering Lake. It also extends up the valley of Shepherd Creek for a distance of about 4 miles above the lake, and apparently to the southern end of Lake Kushtaka. The valley of Katalla River and of the stream which heads near it and flows into Bering Lake is floored with the same material, as are also the lower courses of most other streams which enter Controller Bay. The deposits are known to have a thickness of over 580 feet at one point on Bering River, and of over 240 feet in the Katalla Valley.

Another series of deposits contemporaneous with the last, yet different in origin, are the beaches, islands, and bars which the waves of the ocean are building along these shores. Okalee sand spit and the long beach extending from Strawberry Harbor to the mouth of Katalla River are good examples. Others, which extend out of the region here described, are Softuk Bar and the line of bars and sand hills extending in line with it across the margin of the Copper River delta.

GLACIERS AND GLACIAL DEPOSITS.

The Bering Glacier, previously mentioned as supplying Bering and other rivers, is a large glacier of the Piedmont type, and, if considered independently, is second in size, among glaciers of this type, only to the Malaspina Glacier. It is a large field of stagnant ice, which has overflooded the eastern extension of the zone of coastal foothills described above, and it is considered by many as merely the western lobe of the Malaspina Glacier. It is, however, in all probability entirely separate from the latter. A great many valley glaciers coming from the Chugach Range enter it as tributaries. It is fringed along its southwestern border by a wide moraine, while the ice itself is thickly covered with rock débris for a distance of several miles from its front, and, as in the case of the Malaspina Glacier, this covering is so thick that it is often impossible to determine the margin of the glacier itself. During the warm summers large lakes are formed on the surface of the ice, which later in the season break loose and subject the valleys of the Bering, the Nitchawak, and other streams draining the ice front to severe floods. The entire region from the lower tidal channel of Bering River eastward to the ice front, a distance of over 10 miles, is a great flood plain formed of the débris which these rivers are depositing.

In the region north of Bering River there are a number of valley glaciers not tributary to the Bering Glacier, the best known of which is the Martin River Glacier, which flows northward behind the coal field, and one lobe of which is the Kushtaka Glacier, entering the lake of the same name. There are others to the northwest which have received no names and are unmapped.

STRUCTURE.

DETAILS.

An anticline extends through the Katalla Valley in an average direction of N. 38° E. Exposures on the western flank showed strikes of N. 55° E. and N. 85° E., with dips varying from 18° to 65° NW., on the west shore of Bering Lake; and a strike of about N. 40° E., with a dip of 70° NW., near the mouth of Deep Creek. The strata are almost continuously exposed along the eastern flank in the high ridge forming the eastern side of the valley. The strike varies from north to N. 40° E. and the dip from 32° to 60° SE. The outcrop in the high southern peak of this ridge is an unexplained irregularity, for the strike is N. 30° W., with a dip of 35° SW. From this point a ridge extends northeastward along the eastern side of the Katalla Valley. The strike and dip last mentioned are apparently confined to the southern peak of this ridge, for beyond the first saddle which separates it from the continuation of the ridge the strike is along the crest of the ridge, N. 40° E., with a dip of 35° SE. (See Pl. III.) This ridge is, then, apparently monoclinal, with the exception of its southwestern peak, where the strata have been abruptly flexed or faulted, striking almost at right angles to those in the rest of the ridge.

The exposures on the western shore of Bering Lake show greater uniformity of strike than those hitherto described. The strike varies from N. 55° E. to N. 85° E., while the dip is from 18° to 65° NW. This strike if continued southwestward would carry the same strata and the same structure into the hills on the northwestern side of the Katalla Valley, and would thus make Katalla River occupy an anticlinal area with a northeast-southwest direction. This strike does not seem to continue northeastward across Bering Lake, for the strata on the north shore of the lake apparently belong to a different formation and have a different structure. It is possible, then, that the northwestern arm of the lake occupies the position of a fault which extends north and south parallel to the western shore of the lake. If this fault is continued southward into the region of the hills on the western side of the Burls Creek Valley, it may explain some of the apparently strong variations in the structure within short distances, which have been alluded to above.

In the valley of Burls Creek, however, a great complexity of structural relations exists, almost no two outcrops agreeing, even in the general direction of the strike or dip. The outcrops nearest the shore of Bering Lake, on the western slope of the creek's valley, have a strike of N. 30° E. and a dip varying from 45° to 60° SE. This corresponds in general direction and amount with the strike and dip of the ridge forming the eastern slope of the Katalla Valley, and inasmuch as this hill is in a general way the most northeasterly outlier of this ridge it is possible that it is a part of the same anticlinal fold. In a peak 1 mile to the south an approximate north-south strike was observed, with a dip of 45° to the west. This would seem to lie upon the eastern flank of a syncline whose axis corresponds in a general way with the position of the group of hills occupying the area between Redwood Creek and Mary Creek. This syncline might be considered the northern prolongation of the one shown in the crescent-shaped ridge bordering the northern shore of Strawberry Harbor.

The peninsula from Point Hey to Cave Point consists of a crescent-shaped ridge, its concave face toward the sea, and forming the northern shore of Strawberry Harbor (Pl. III). The dip is everywhere toward this concavity, changing from southwest at Point Hey to southeast at Cave Point, indicating the presence of a pitching syncline, of wihch only the nose is on land.

An outcrop at the lower edge of the abrupt slope rising from the tidal flat about halfway between Burls Creek and Mary Creek has a strike N. 55° E. and a dip of 52° NW. This would not seem to readily fit into any of the general structure hitherto described, and can only be explained at present as a local variation in the eastern flank of the above-mentioned syncline. (See Pl. III.)

Chilkat Creek, which occupies the valley between Bering River and Burls Creek, has exposed a great many excellent outcrops. It is evident that a sharp anticline extends along the general line of this valley from northeast to southwest, the dip of the flanks averaging about 45°. The center of the anticline is very steep and locally crumpled. The ridge east of this valley, between it and Bering River, is apparently synclinal, with a strike of about N. 40° E. This fold is very sharp along its axis, for the rocks at the mouth of Bering River stand vertical, though farther up the river the dip is 40° NW.

The strike of the coal formation is, in general, from northeast to southwest; and the dip is to the northwest. There are certain variations, but they appear to be due to local disturbances. The structure of the region as now known is chiefly monoclinal. The continuation of this feature to the southwest would carry the coal into the hills on the west shore of Bering Lake and on the west bank of Katalla River. No coal is known, however, in these hills, and the shales exposed on the west shore of the lake appear to be identical with those on the south shore, which have been described in the preceding chapter as the Katalla formation. It is evident, therefore, that there is a line of faulting through the north end of the lake and parallel to the west shore. The coal is apparently absent to the west of this fault. It would appear from the dip that the Kushtaka formation overlies the Katalla formation; there is, however, no positive proof that such is the case. No contact of the two has been observed, and there is no reason why other explanations of the existing phenomena may not be found.

The monoclinal dip, which has been observed as continuing for several miles up the valley of Canyon Creek, would seem to indicate a thickness of many thousand feet in the Kushtaka coal measures. Several faults, however, were observed in the banks of Canyon Creek, and it may be that these are numerous enough or of sufficient displacement to cause the thickness of the formation to appear greatly increased.

This monoclinal dip is apparently modified by only two folds within the region hitherto explored. There is one fault which probably has considerable length and displacement, and an undetermined number of smaller ones.

One of these folds is an incline exposed near the headwaters of Queen Creek on the divide between the Shepherd Creek and Lake Kushtaka valleys. The rocks here have a strike of N. 64° to 66° E., with a dip of 42° NW. on the northwest flank of the fold, and 58° SE. on the southeast flank. The latter is cut by a fault of unknown but probably of considerable magnitude. The other is a sharp syncline, which apparently lies in the hills east of Lake Charlotte. Its presence is indicated by the fact that the dip of the Charlotte seam at the openings above the lake is southeast. It is not known how far in either direction this southeast dip continues.

A northeast strike and a northwest dip, corresponding to many of those alluded to above, may be seen on Kayak and Wingham islands and in the hills of the Nitchawak region. Each of these areas considered independently is therefore monoclinal. The intervening areas, where the solid rock is concealed by water or lowland, are so broad that the general structure can not be made out.

The rocks on the shore of the mainland near Fox Island, and apparently those of the islands themselves, have a strike of N. 70° W., parallel to the shore, with a steep seaward dip. The high ridge northeast of this point seemingly consists of rocks standing almost vertical, with a north-south strike parallel to the ridge. On Lone Baldy Mountain, about 3 miles north of Fox Islands, the strike is N. 80° E. and the dip 80° NW. The high ridge about 2 miles north of this point apparently has a strike parallel to this and a steep dip. The relation of this dip to that observed at Fox Islands and on the ridge northeast of them has not been determined.

GENERAL FEATURES.

It can be seen from the statements given above that the structure of this region is very complex, at least so far as the minor details are concerned. The outcrops are almost wholly confined to the higher ridges and to the deep canyons. Many of the latter were almost inaccessible to the author on account of the amount of snow and ice at the time of his visit. The observations are, therefore, not numerous and are widely scattered. It is probable that a large proportion of these observations do not represent the major structure of the region, but rather a minor crumpling which is attendant upon the dominant, simpler, structure. This major structure can be made out only by platting so large a number of observations that the entire structure will be evident, both in its broader features and in its less essential and diverse details, or else by determining some characteristic strata whose general position of outcrop can be readily followed, and which can be made to thus give the key to the major structure. Unfortunately the rocks of the Katalla formation are so homogeneous throughout that no strata have been so far observed which are characteristic enough to make the dominant structure evident, and the observations which have been made are not abundant enough to determine the complete structural relations as suggested for another method.

There appears to be a larger folding, modified by a minor folding, that often reveals itself merely as a crumpling in the softer shales but which is locally so strongly developed as to obscure the major folding. There are thus two sets of structural features, one of which reveals itself in an east-west and the other in a northeast-southwest strike. The first is well shown in the great anticline which is described below as extending along the coast at Cape Yaktag; and it again appears in some of the exposures of this region, especially along the coast near Katalla. Of the second series of folds, those extending in a direction from northeast to southwest, one of the most illustrative is the anticline which apparently extends along the center of the Katalla Valley. This is paralleled by a number of other folds east of it in the peninsula between Bering Lake and Controller Bay, one of the most distinct being the anticline in the little valley nearest Bering River. The central part of the peninsula appears to consist of a succession of folds, several of which are exposed in the valley of Burls Creek.

The structure of this region appears at first sight to be extremely complex, the strikes and dips being of almost indescribable irregularity. More careful studies made during the summer of 1904, have, however, shown that part of the irregular outcrops are of large blocks which have been displaced by gravity on the steep hillsides, while part of them may be assigned to a minor crumpling in the softer beds. Others may be due to faulting, but the amount of influence of this factor is not known.

After the irregularities due to the above-mentioned cause have been eliminated, the following structural features distinctly appear. The prevailing strike is northeast and southwest and the prevailing dip is from 35° to 60°. The region between Bering Lake and Controller Bay consists of an undetermined number of parallel, closely folded anticlines and synclines, with pitching axes of which the average direction is N. 35° E. The most plainly developed of these folds are the Katalla Valley anticline, the Strawberry Point syncline, and the Chilkat Creek anticline.

The structure of that part of the coal area which was visited by the writer is rather simple. The strike is fairly regular in direction (northeast and southwest), and the dip is chiefly northwestward. The uncertain factor is the total amount of influence of the faults.

ECONOMIC MATERIALS.

PETROLEUM.

Petroleum seepages.—Petroleum seepages are very abundant in the Controller Bay region. Those which are best known are situated about 4 miles east of Katalla. The flow of oil here is very large, and good-sized pools have collected on the surface. Another group of seepages is on the headwaters of Burls Creek, where the petroleum may be seen oozing from the joints and bedding planes of the carbonaceous shales and volcanic ash beds which are exposed in the deep ravines. The quantity of petroleum here showing is not so large as at the seepages east of Katalla, but it is more widespread. The small stream between Burls Creek and Bering River has several seepages along its bank. Seepages occur, too, in other parts of the peninsula between Bering Lake and Controller Bay and in the region west of Katalla. The so-called "Nitchawak region," which is situated on the banks of the various branches of Nitchawak River and in the vicinity of Mount Nitchawak, also presents a number of seepages. Some of these are located on the banks of a small lake, which is reported to be at times covered with petroleum. The small creeks which enter Little Nitchawak River from the north have a number of seepages on their banks, in some of which oil issues directly from the rock, which is here a shale. The canyon north of Lone Baldy Mountain and between it and Ragged Mountain contains a number of seepages, in which the oil may be seen oozing from the cracks of the rock.

A strong flow of gas bubbles to the surface of the water at a number of places along the lower course of Katalla River. In places this flow is so strong that it can be heard for a distance of several hundred feet. The composition of the gas is not known. Several large sulphur springs issue from the northern bank of Bering River within a mile on either side of the Indian village.

Most of the seepages between Katalla and Bering River fall approximately on three straight lines, each having a general northeast-southwest direction. These lines are nearly parallel to the strike in their vicinity, and are undoubtedly influenced in position and direction by the structure. They probably represent the outcrops of oil-bearing strata. The easternmost of them is on the western flank, but very close to the crest of the Chilkat Creek anticline. The westernmost is on the eastern flank and about halfway down the Katalla anticline. Those in the valley of Burls Creek are in a less certain structural position.

The gas springs on the banks of Katalla River are probably located on or near the crest of the Katalla anticline.

Petroleum wells.—The first well in the Controller Bay region was drilled in the summer of 1901. Work upon it was stopped owing to the loss of tools. The same company drilled another well in the summer of 1902, which at a depth of about 250 feet yielded some petroleum. At a depth of 360 feet the tools appeared to break through into a cavity of the rock and a large flow of oil began, spouting, it is reported, many feet above the top of the derrick. No estimate of the amount of the flow has been made. This well was immediately capped, to be reopened in July, 1903, and drilled deeper, and it is now reported to have a total depth of 550 feet.

The following is a record of the well as reported by the Alaska Steam Coal and Petroleum Syndicate, and published by Mr. F. H. Oliphant:[a]

Well record near Controller Bay.

	Depth, in feet.
6 feet surface drift	6
10 feet decomposed shale	16
140 feet light-colored shale	156
18 feet fine-grained sandstone	174
One-half foot coal contained in the sandstone	174½
190 feet dark shale, very hard	364½
One-half foot quartz containing iron pyrites, and contained in the shale	365
1 foot oil sand and flow of oil	366
Total	366
Length of 12-inch casing	220
Length of 9⅝-inch casing	340

Numerous small showings of petroleum and natural gas were encountered as the drill proceeded, and at 366 feet a large flow of oil was developed. The well is said to have continued to flow until capped.

Another company began work in the spring of 1903 on a well about 4,000 feet south of the first producing well mentioned above. In July this well was abandoned at a depth of 1,700 feet, that being as far as it was possible to drill with the light rig which was used. No flow of oil was encountered, but a little was brought up in the bailer from time to time.

It should be noted, in comparing the results obtained in these two wells, that the location of the second with reference to the first is in the direction of the dip. The dip is very steep in the interval of 4,000 feet between the wells, and while the exact amount is undetermined it is surely enough to carry the oil sand that was tapped in the first well to a depth considerably exceeding 3,000 feet at the location of the second.

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[a] The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

Another well on the north bank of Katalla River, about 2 miles above the town of Katalla, was begun by the same company during July, 1903. The latest information which the author has received is that it was drilled to a depth of 240 feet without reaching solid rock. A third company began drilling in July 1903, about 7 miles above the mouth of Bering River. At last reports this well had attained a depth of 580 feet and bed rock had not been reached.

Fifteen wells had been drilled or were drilling in this region in September, 1904. Of these, two are in the Katalla Valley, one is 3 miles east of Katalla near Cave Point, two are on Strawberry Harbor, nine are between the head of Katalla Slough and the mouth of Bering River, and one is on Bering River about 4 miles above its mouth. Of these wells, three (one in the Katalla Valley, one on Strawberry Harbor, and one on Bering River) were abandoned before reaching bed rock. Four of them (one in the Katalla Valley, one at Strawberry Harbor, and two west of the mouth of Bering River) are still drilling. Of the remaining eight wells, three were mentioned in an earlier report.[a] One of these is now furnishing oil which is used as fuel at the other wells of the same company. No statistics regarding the present production of the well are at hand, nor is it known how much greater the yield might be if the well were pumped continuously.

The amount of authentic information which has been given out for publication regarding these wells is extremely small.

It is reported that none of the remaining five wells has produced oil in commercial quantities. But it is furthermore said that none of them has reached a depth exceeding 1,100 feet, in which case it may be assumed that the possibilitites of the field have not yet been conclusively tested.

Mr. F. H. Oliphant, in summarizing the developments during 1903, said of this field:[b]

"The developments in Alaska during 1903 have not resulted in any commercial production of petroleum, notwithstanding the numerous surface indications and the wells that have been completed in the supposed productive territory. The prospectors should not, however, be discouraged, although it may require patience and careful prospecting with the drill to tap the reservoirs, whose existence seems to be indicated by remarkable surface shows of both petroleum and natural gas."

Great difficulty has been experienced in all parts of the field in keeping the holes straight and free from water. This has made progress very slow and deep drilling sometimes impossible. Perhaps some of the wells would have been more successful if they could have been continued to greater depths.

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[a] Bull. U. S. Geol. Survey No. 225, 1904, pp. 368–369.

[b] The production of petroleum in 1903: Mineral Resources U. S. for 1903, U. S. Geol. Survey, 1904, p. 690.

Three wells which were located on mud flats at some distance from high land or from exposure of solid rock had difficulty or did not succeed in reaching bed rock. In two cases the drivepipe was sunk to depths of 240 and 580 feet through mud without reaching solid rock. These instances show conclusively the inadvisability, in the present stage of development, of attempting to locate wells on the flats. After a field is proven, then the mud flats adjoining it longitudinally may be considered to have a speculative value. At present there is no indication that they are worth anything.

Another instance illustrating the folly of investing in the low grounds, and also of investing without thorough investigation, is the case of a tract which was staked and sold for $1,700 during the past winter. In the spring the supposed land floated and melted entirely away, the stakes having been driven in the ice off the shore of Controller Bay. It is generally believed in the region that there was no intent to defraud.

Structural relations of the petroleum.—The conditions believed by the majority of observers to be necessary to the occurrence of petroleum in commercial quantities are, first, the presence, originally, of a large amount of organic matter in the sediments from which the oil was derived; second, the existence of a porous rock, in the aggregate very considerable, in which the oil could accumulate, and, third, the protection of this rock in such a manner that the oil can not escape. The condition generally regarded as affording the most efficient protection is the presence of an overlying stratum of fine compact rock which the oil can not penetrate and the flexure of the strata into a gentle anticline, so that escape of the oil is cut off both in an upward direction and laterally—in the latter case, it may be, by the body of water behind it. Other conditions which govern the accumulation and distribution of oil are changes in the porosity of the containing bed, either from variation in the coarseness of sediment or from the filling of the interstices with mineral deposits, such as carbonate of lime. Underground water also doubtless plays a part in the accumulation and distribution of oil.

From the size and distribution of the seepages it may be reasonably inferred that a vast amount of organic matter which was subsequently converted into petroleum was incorporated with the sediments now constituting the oil-bearing shales of the Controller Bay region; the appearance of the rocks is evidence that there are numerous horizons in the series sufficiently porous to afford reservoirs for the accumulation of oil, and the successful wells show that the conditions are favorable for at least one productive field. Conditions below the surface are, however, frequently very difficult even to surmise, and the aid ordinarily derived from well records is not yet sufficient in this field to show conclusively the relation in depth between the occurrence of the oil and the structure and stratigraphy of the containing series. The structure of the field is complex, but if drillings are made after a careful consideration of all geologic details the existence of valuable oil areas may perhaps soon be proved and their definition safely suggested.

CAPE YAKTAG PETROLEUM FIELD.

Cape Yaktag is situated about 75 miles east of Controller Bay. The shore line is here straight, and there is no harbor which affords shelter for any kind of boat. (See fig. 1.) A strip of land from 5 to 10 miles in width lies between the coast and Bering Glacier. The ice front is marked by a line of hills which are parallel to the coast and from which a steep slope descends to the sea. This slope is drained by many short parallel streams, some of which head in the ice. The Cape Yaktag oil field extends eastward for about 25 miles from the mouth of Yaktag River, which is the easternmost of the longer streams reaching the ocean near Cape Yaktag (fig. 1).

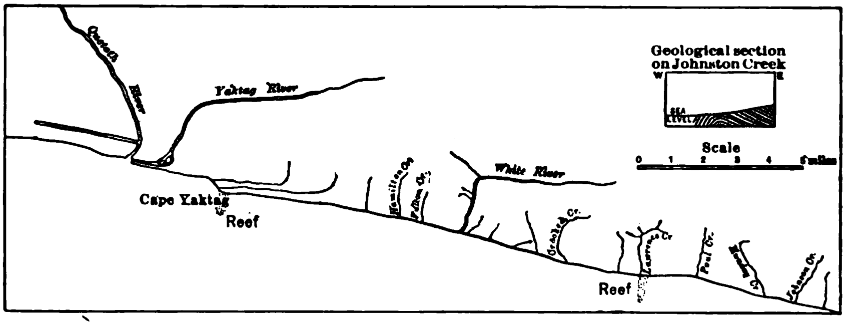

FIG. 1.—Sketch map of Cape Yaktag petroleum field.

Geology.—The writer was not able to visit this region, so that the following observations are based upon the statements of others: The structure, it is said, is anticlinal, with the axis parallel to and very near the shore line. The dip on the southern flank of the fold is very steep, the rocks standing vertical along the beach. The dip on the northern side in much gentler, seldom exceeding 20°. This continues inland as far as the region has been explored. The rocks consist of shales with interbedded sandstone and limestone, the whole resembling very closely in lithologic character some of the rocks of the Controller Bay oil field. They here carry fossils which show them to be of Miocene age. A list of these fossils was published by Mr. J. E. Spurr.[a] The structure of the region is very uniform, and no marked variations from the strike and dip recorded above were noticed.

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[a] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 264.

Occurrence of the petroleum.—There are said to be good seepages in several of the creeks in this belt, and the petroleum is regarded as similar in character to that of the Controller Bay field. It oozes from the rocks along the crest of the anticline. No development work has been done, due to the difficulty of transporting machinery, which it would be necessary either to land through the surf on the open coast or to transport overland for a distance of 75 miles from Controller Bay. The latter will be an impossibility until roads are constructed.

COAL.

BERING RIVER COAL FIELD.

The field.—The Bering River coal field lies from 12 to 25 miles inland from Controller Bay. The coal area, as far as known, is restricted to the region north of Bering Lake and Bering River. Its southern boundary appears to coincide approximately with the position of Bering Lake and with Bering River above the lake. The western boundary, although not definitely known, is assumed to lie along a north-south line extending through the northwest arm of Bering Lake parallel to its western shore. The northern and eastern boundaries are also uncertain, but are probably at a considerable distance beyond the region as now known. The coal area as at present recognized includes about 120 square miles. (See Pl. III.)

The coal is known to extend as far north as the Martin River Glacier and as far east as the valley east of Carbon Mountain. It is possible that further exploration will reveal the presence of coal north of the Martin River Glacier in the foothills of the Chugach Mountains or in the region to the east of Carbon Mountain.

The lowlands which border the northeast shore of Bering Lake and extend up Shepherd Creek, Bering River, and other streams are doubtless underlain by coal. The covering of mud and other soft deposits is probably very thick, and the uncertainties of deep mining below it are so great that these lands are now of very doubtful value. The same applies to the area covered by the Bering, Martin River, and Kushtaka glaciers. The above estimates of the coal area include only the high land lying above and between the tidal flats and river flats and the glaciers.

Geologic occurrence of the coal.—The coal is restricted to the rocks of the Kushtaka formation described above. The following local sections have been measured by the writer:

Section in lower tunnel on east bank of Carbon Creek.

	Feet.
Dark shale	2
Coal	20
Massive, arkosic, cross-bedded sandstone with many thin carbonaceous streaks	10

The strike at this point is N. 65° E. The roof of the seam dips 60° NW., the floor 78° NW.

About 100 yards northwest of this point a seam containing about 3 feet of clean coal has been exposed. One mile northwest, at what is known as Doyle Camp, a coal 20½ feet thick is exposed. The strike of the roof is N. 10° E., of the floor N. 30° W.; the dip is from 75° to 85° E. Both roof and floor are very irregular and the coal has been found to be entirely cut off by a fault.

Several seams have been opened near the headwaters of Shepherd Creek, of which the most promising is the Charlotte seam, on the hillside southeast of Lake Charlotte.

Section of the Charlotte seam.

Shale roof	10 ft.+	
Coal		2 in.
Shale		5 in.
Coal	9 ft.	6 in.
Shale and coal	6 ft.	

Strike, N. 12° E.; dip, 72° SE.

The same seam has been opened again about half a mile south of this point. The coal in this seam is firmer and should stand shipment with less crushing than any other seen by the writer in this field.

Section 1 mile northwest of Canoe Landing on Shepherd Creek.

	Ft.	In.
Coal	3	0
Shale	0	2
Coal	4	4

The strike at this point is N. 20° E., the dip 65° NW. The opening is on the west side of the valley of Shepherd Creek, at an elevation of about 200 feet above Bering Lake.

The region adjoining the north shore of Bering Lake has been exploited to a considerable extent during the past season and a small amount of coal mined for local use. The seams so far discovered in this region are smaller than those described from other parts of the field.

The high ridge between Lake Kushtaka and Shepherd Creek contains a large number of seams. There are probably at least 20 of these seams which are 5 feet or more in thickness and several which are over 20 feet thick.

The western slope of this ridge is drained by Queen Creek and other branches of Carbon Creek. Queen Creek has cut into the crest of a sharp anticline, which is probably faulted on its southeastern flank, and on both flanks of which coal seams are exposed. The coals in this locality are of extraordinary thickness, perhaps having swollen into pockets near the crest of the field. (See fig. 2.)

Section of coal on northwest bank of Queen Creek.

	Feet.
Shale roof.	
Coal	27
Shale (pocket?)	7
Coal	2
Shale	10
Coal	31
Shale floor.	

Section of coal on southeast bank of Queen Creek.

	Ft.	In.
Coal	14	0
Shale	4	0
Coal	7	0
Shale	0	3
Coal	2	0
Shale	0	2
Coal	10	0

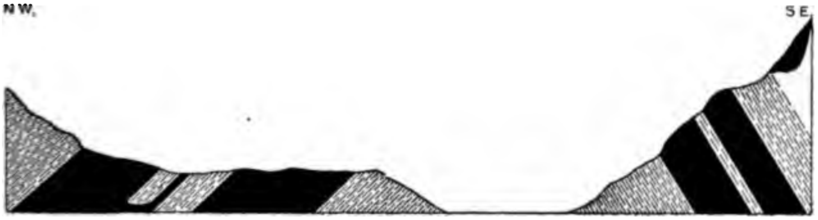

FIG. 2.—Section on Queen Creek, showing structure and coal seams. Scale, 1 inch = 75 feet.

Several prospect openings and a well-constructed tunnel have been driven into the banks of Carbon Creek. The latter intersected two seams, the larger of which has a thickness of 8 feet of clean coal. This is not the same as the Carbon Creek tunnel mentioned above.

The valley of Stillwater Creek and Lake Kushtaka has been shown to contain a great deal of valuable coal. A trail recently built northward from the western shore of Lake Kushtaka exposes 15 or 16 seams. The writer has seen one seam on the west side of Lake Kushtaka which has a thickness of over 22 feet, and several others with thicknesses of from 8 to 15 feet. It is reported that a thickness of over 60 feet of coal was found in a tunnel in one of the valleys on the north side of Stillwater Creek.

The following section is exposed in the west bank of Trout Creek, 2 miles above its juncture with Stillwater Creek and 6 miles above the mouth of the latter:

Section on Trout Creek.

	Feet.
Shale	4
Coal	6½
Sandstone	5

The strike is N. 40° E., the dip 38° W.

Several valuable seams have recently been opened in the valley of Canyon Creek and on the opposite (east) side of Carbon Mountain. It is said that of fifteen openings in the same seam on Carbon Mountain which showed a range of thickness from 9 to 25 feet, nine revealed a thickness of 14 feet or more. About a dozen workable seams have been reported from this region. The writer has already published the following sections of the coal and coke seen by him in this vicinity,[a] which were all that were accessible when he was there in 1903.

Four seams are exposed on the east bank of Canyon Creek. Three miles above the mouth the coal has a thickness of 2 feet 9 inches, is overlain by sandstone, and has a shale floor. The strike is N. 80° E., the dip 35° W. The section was measured at the level of the valley floor. This seam is variable in thickness, pinching out somewhat higher in the bluff.

Four miles above the mouth of Canyon Creek a coal has a thickness of 4 feet 2 inches; it strikes N. 10° E. and dips 60° W., and has a shale roof and floor.

At the south end of Carbon Mountain there is a high bluff where Bering River has been pushed against the end of the mountain by the Bering Glacier, and here the following section was measured:

Section at south end of Carbon Mountain.

	Feet.
Sandstone	30
Coke	1
Sandstone	20
Coke	2
Sandstone	2 to 5
Coke	1 to 5
Sandstone	3
Coke	1
Sandstone	8
Coke	1¾ to 2¼

The strike at this point is N. 80° W., the dip from 20° to 25° N.

It is the opinion of the writer that the foregoing sections represent distinct coals, and that, furthermore, from the smut observed by him, many additional ones will be discovered in the development of the country which are now concealed beneath the soil and the dense vegetation.

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[a] Bull. U. S. Geol. Survey No. 225, 1904, p. 372.

Owing to the general northerly dip throughout the coal field, the northern portion of it, as at present recognized, is underlain by a far greater number of seams than the southern. But the northward extent of the field, the nature of its structure, and the manner of its termination remain unknown.

The features to be considered by the mining engineer embrace faults and their attendant problems, steep dips, the proportion of the seams above water level, accessibility, and the physical properties of the coal as affecting its shipment and market value, a tendency to crush being especially noticeable.

The lands within the region noted above as known to be coal bearing have for the most part, if not entirely, been located, and it is understood that some of the holders are about to secure patents. It seems probable that there are unlocated coal lands in the unexplored area to the east and northeast.

The work which has been done in the development of this field is entirely pioneer development work. Land surveys have been made of most of the larger holdings. Several railway routes have been surveyed. Many miles of good trails have been built, and a large number of cabins erected. A large number of prospect openings have been made and several more extensive tunnels dug. There is a tramroad and a gravity plane from Shepherd Creek to a tunnel on the hillside to the westward. A small amount of coal is being mined for local use in stoves and as blacksmith coal at some of the neighboring oil wells.

More extensive mining will be delayed until shipping facilities are provided at Controller Bay or elsewhere, and a railroad is built from the harbor to the mines.

Character of the coal.—The physical properties of the coal are very much alike in all the seams and in all parts of the field visited by the writer. The coal resembles the harder bituminous coals of the East more than it does anthracite. It is doubtful, too, if much of the coal could be sized so as to compete with anthracite coal for domestic use; and again, under ordinary handling it will probably crush to almost the same extent as the harder grades of semibituminous coal, which will not, of course, impair its value for steam purposes, but will necessitate careful handling if it is to at all compete with Pennsylvania or Welsh anthracite as a domestic fuel.

The following table includes all the analyses and calorimetric tests which have been made of the Bering River coal. The first nine samples were collected by the author and represent the composition of the entire seam; that is, coal was cut evenly from the seam, from roof to floor.

Analyses and tests of Bering River coals.

Locality.	Thickness of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Color of ash.	Calories.	Recalculated.		
									Fuel elements.		Fuel ratio.
									Volatile matter.	Fixed carbon.	
	Feet.										
1. Carbon Creek[a]	20	2.41	15.08	79.24	3.32	0.51	Reddish	8,345	15.94	84.06	5.27
2. Shepherd Creek[a]	7½	1.54	14.58	72.99	10.89	.69	Yellow	7,664	16.65	83.35	5.01
3. Trout Creek[a]	6½	2.36	18.12	71.87	7.65	.73	Reddish	7,819	20.14	79.86	3.97
4. Canyon Creek[a]	4½	3.24	9.79	62.97	24.00	1.94	Yellow	6,502	13.45	86.55	6.43
5. South end of Carbon Mt. (coke).[a]	5	1.34	6.30	84.57	7.79	.77	Very red.	7,776	6.93	93.07	13.43
6. Queen Creek[b]	31	1.20	17.28	77.69	3.83	.78	Reddish	8,310	18.20	81.80	4.49
7. Queen Creek[b]	27	.56	16.61	78.71	4.12	1.25	Reddish	8,310	17.43	82.57	4.74
8. Lake Charlotte[b]	9½	.68	17.87	60.73	20.72	.55	Gray	6,883	22.74	77.26	3.40
9. Carbon Creek[b]	8	.38	16.97	77.48	5.17	1.02	Gray	8,248	17.97	83.03	4.57
10. Bering River[c]	......	.83	7.18	87.57	4.42	......	....	......	7.58	92.42	12.19
11. Bering River[d]	......	1.00	14.30	81.10	3.60	......	....	......	14.99	85.01	5.67
12. Controller Bay[e]	......	.75	13.25	82.40	3.60	.69	....	8,376	13.85	86.15	6.22
13. Controller Bay[e]	......	.78	13.22	80.30	5.70	2.90	....	8,043	14.13	85.86	6.07
14. Bering River[f]	......	.77	13.79	82.36	3.08	2.68	Brownish.	8,289	14.34	86.66	5.97

[a] Sample collected by G. C. Martin. Analysis and calorimeter test by Penniman and Browne.

[b] Sample collected by G. C. Martin. Analysis by E. C. Sullivan.

[c] Analysis by William H. Fuller, Fairhaven, Wash. Published by John Kirsopp, jun., The coal fields of Cook Inlet, Alaska, U. S. A., and the Pacific coast: Trans. Inst. Min. Eng., vol. 21, 1901, p. 570.

[d] Analysis by W. F. Robertson, Victoria, B. C. Published by John Kirsopp, jun., as above.

[e] Analysis furnished by F. H. Shepherd. Published by J. E. Spurr, A reconnaissance in southwest Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, p. 263. (No. 13 is not from Icy Bay as hitherto reported.)

[f] Sample collected by W. M. Carless. Analysis by W. F. Hillebrand. Published by Schrader and Spencer, Geology and Mineral Resources of a portion of the Copper River District, Alaska, p. 91.

NOTE.—The calories of Nos. 6 to 14 are computed from the analysis by the author.

The above coals vary greatly in composition and in heating power, and it seems likely that this field, as elsewhere, each seam will be found to have a characteristic composition. The source of Nos. 10–14 is not known, but possibly some of them are from the opening on Carbon Creek from which No. 1 was obtained. The difference between the amount of moisture in these samples and that in sample Nos. 1–5 is probably due to the fact that the latter were placed in sealed cans as soon as taken and no opportunity was given for the coal to dry out. The very high percentage of sulphur in Nos. 13 and 14 is probably due to their having been taken, not from the entire thickness of the seam, but from pieces of coal which were picked for their hardness and apparent cleanness. The one who took the samples evidently overlooked the fact that their exceptional hardness was not due to the coal being nearer anthracite, but to its containing a large amount of pyrite (sulphide of iron).

Analyses of other coals for comparison.

Locality.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Calories.	B. T. U.	Recalculated. Fuel elements. Volatile matter.	Recalculated. Fuel elements. Fixed carbon.	Recalculated. Fuel ratio.
Pennsylvania, anthracite (average of 9)[a]	3.389	3.812	83.790	8.417	0.592	......	....	4.35	95.65	21.99
Wales, anthracite (average of 4)[b]	......	5.94	91.42	2.62	......	......	....	6.11	93.89	15.80
Loyalsock, semianthracite (average of 4)[c]	1.488	11.074	78.883	7.695	.861	......	....	12.31	87.69	7.12
Pocahontas, semibituminous (average of 88)[d]	.73	17.43	77.71	4.68	.62	8,408	15,178	18.32	81.68	4.46
Georges Creek, semibituminous (average of 12)[e]	.69	18.95	74.11	6.08	.67	7,984	....	20.36	79.64	3.91
Georges Creek, semibituminous (No. 9023)[e]	.65	17.89	74.28	6.18	.60	......	....	19.41	80.59	4.15
Georges Creek, semibituminous (No. 9011)[e]	.72	18.61	75.06	5.61	.71	8,144	....	19.87	80.10	4.03
Georges Creek, semibituminous (No. 9004)[e]	.67	18.19	72.41	8.73	.66	7,708	....	20.08	79.92	3.98
Georges Creek, semibituminous (No. 9002)[e]	.69	20.16	71.59	7.56	.55	7,983	....	21.97	78.03	3.56
Pocahontas (Quinnemont), semibituminous (average of 17)[f]	.60	19.93	75.20	4.27	.67	8,415	15,202	20.95	79.05	3.77
New South Wales (southern coal fields), bituminous (average of 21)[g]	.97	23.10	65.26	10.67	.462	......	....	26.14	73.86	2.83
Wales, bituminous (average of 87)[h]	......	27.00	68.09	3.22	1.43	8,402	....	28.39	71.61	2.52
Comox, bituminous (average of 4)[i]	1.30	28.63	62.73	6.96	......	......	....	31.35	68.65	2.19
Naniamo, bituminous (average of 4)[i]	2.19	30.76	56.52	10.53	......	......	....	35.24	64.76	1.84
New South Wales (western coal field), bituminous (average of 13)[j]	1.87	31.49	52.61	14.03	.626	......	....	37.44	62.56	1.67
New South Wales (northern coal field), bituminous (average of 77)[j]	1.92	35.09	54.08	8.91	.541	......	....	38.23	61.77	1.62

[a] Ashburner, C. A., Ann. Rept. Geol. Survey Pennsylvania, 1885, p. 313.

[b] Lozé, Ed., Les Charbons Britanniques et leur Épuisement, vol. 1, p. 386.

[c] Ashburner, C. A., Ann. Rept. Geol. Survey Pennsylvania, 1885, p. 318.

[d] White, I. C., Geol. Survey West Virginia, vol. 2, pp. 695, 698, 700.

[e] These are furnished by Dr. W. B. Clark, State geologist of Maryland, and will be published in a forthcoming report of the Maryland Geological Survey on the coal of that state.

[f] White, I. C., Geol. Survey West Virginia, vol. 2, p. 670.

[g] Pittman, E. F., Mineral Resources of New South Wales, 1901, pp. 324–348.

[h] Poole, H., The Calorific Power of Fuels, 1898, p. 223.

[i] Dawson, G. M., Mineral Wealth of British Columbia: Geol. Nat. Hist. Survey Canada, new ser., vol. 3, pt. 2, p. 98 R.

[j] Pittman, E. F., Mineral Resources of New South Wales, 1901, pp. 324–348.

The seams now exposed in the valley of Shepherd Creek are the most promising coals seen by the writer. They not only possess the greatest thickness and are largely free from bands of shale and other impurities, but, as the above table shows, are the purest coals and have the highest heating power. Its composition shows it to be nearly semianthracite, of somewhat the composition of the coal of the Bernice basin (Loyalsock) in Pennsylvania, although it is purer and has a higher heating power than that coal. It differs from the anthracite of Pennsylvania and Wales in having more volatile matter in proportion to the amount of fixed carbon. In the ratio of fixed carbon to volatile matter it is nearer to the Bernice basin coal than to any other coal that reaches the general market. It is almost identical in heating power, as well as in the low amount of impurities, with the Pocahontas steam coal of West Virginia, but excels this coal by having a higher proportion of fixed carbon. There is no other coal with which it is likely to come into general competition with which it is to be compared, for it is far higher in heating power and in purity than any coal that is mined on the Pacific coast, whether in the United States, in Canada, or in Australia.

The seams opened 1 mile northwest of Canoe Landing on Shepherd Creek, and also near the headwaters of Trout Creek, are probably representative of the thinner seams of this region. These coals differ from the coal of the 20-foot seam in having a less amount of fixed carbon in proportion to the volatile matter and in having a higher percentage of ash and sulphur. The heating power is consequently less. They resemble coals of the semibituminous type that enter the market as high-grade steam coals. They correspond in texture, composition, and heating power to the high-grade Pocahontas (West Virginia) and Georges Creek (Maryland) steam coals, and also to some of the semibituminous coals of Wales.

The coke exposed in the southern end of Carbon Mountain is an interesting deposit, which may prove of considerable value. The analysis shows it to be of great purity and high heating power. It will be seen from the section given on page 30 that it is broken up by partings into a number of thin seams, which vary considerably in thickness within short distances. It may be that some of these will be found sufficiently thick and persistent to be of economic importance. Part of the coke is dense and hard and shows a well-marked columnar structure. The latter will break into fine fragments on handling, and will thus be at a disadvantage from the market standpoint. The product should be carefully screened and then the lump will make a domestic fuel of high grade.

Methods of shipment.—There is now no local market for the coal of this field, which therefore necessitates shipping for long distances. It is out of the question to think of building railroads to a market, because of their length, the difficulties and expense of railway construction, and the ease of water transportation. The available harbors are Controller Bay and Katalla Bay, and each of these has its disadvantages. The water of Katalla Bay is apparently very deep to a short distance from the shore, though it is said to be obstructed by an uncharted bar, and it is at present not known how firm the anchorage would be. The bay is, however, exposed to winds from the south. It is said that even the largest ships can run in close to the eastern shore of Fox Islands, where they would be sheltered from all winds except those coming from a little east of south.

Controller Bay has the disadvantage of being shallow over a large part of its area and of being filled, at certain seasons of the year, with drift ice brought down Bering and other rivers from the Bering Glacier. The present steamer landing is at the village of Kayak, on the eastern shore and near the southern end of Wingham Island. The ships enter through a narrow passage between Kayak and Wingham Island, over a bar only to be crossed at half or full tide. There is another anchorage off the northern end of Wingham Island; though accessible at all times, it is farther from shore and directly in the track of the drift ice.

There are several possible routes of transportation from the mines to the harbors. The most direct route from Katalla Bay to the coal fields would be in a straight line up the western side of Katalla Valley, over Katalla Pass (only a few scores of feet above tide), along the west shore and northern end of Bering Lake, and up the western side of the valley of Shepherd Creek. From the coal openings in the headwaters of Shepherd Creek the road could be extended, around the edge of the flat land which forms the peninsula between Shepherd Creek and Bering River, into the valley of Lake Kushtaka; thence down the valley of Stillwater Creek, up Trout Creek, and finally up Bering River and Canyon Creek. Such a road, with branches to reach all the existing coal openings, would be about 44 miles in length, divided as follows:

Routes of transportation between mines and harbor, Katalla Bay.

	Miles.
Fox Islands to mouth of Shepherd Creek	20
Mouth of Shepherd Creek to coal openings on Carbon Creek	6
Mouth of Shepherd Creek to mouth of Stillwater Creek	8
Mouth of Stillwater Creek to coal openings on Trout Creek	4
Mouth of Stillwater Creek to coal openings on Canyon Creek	6

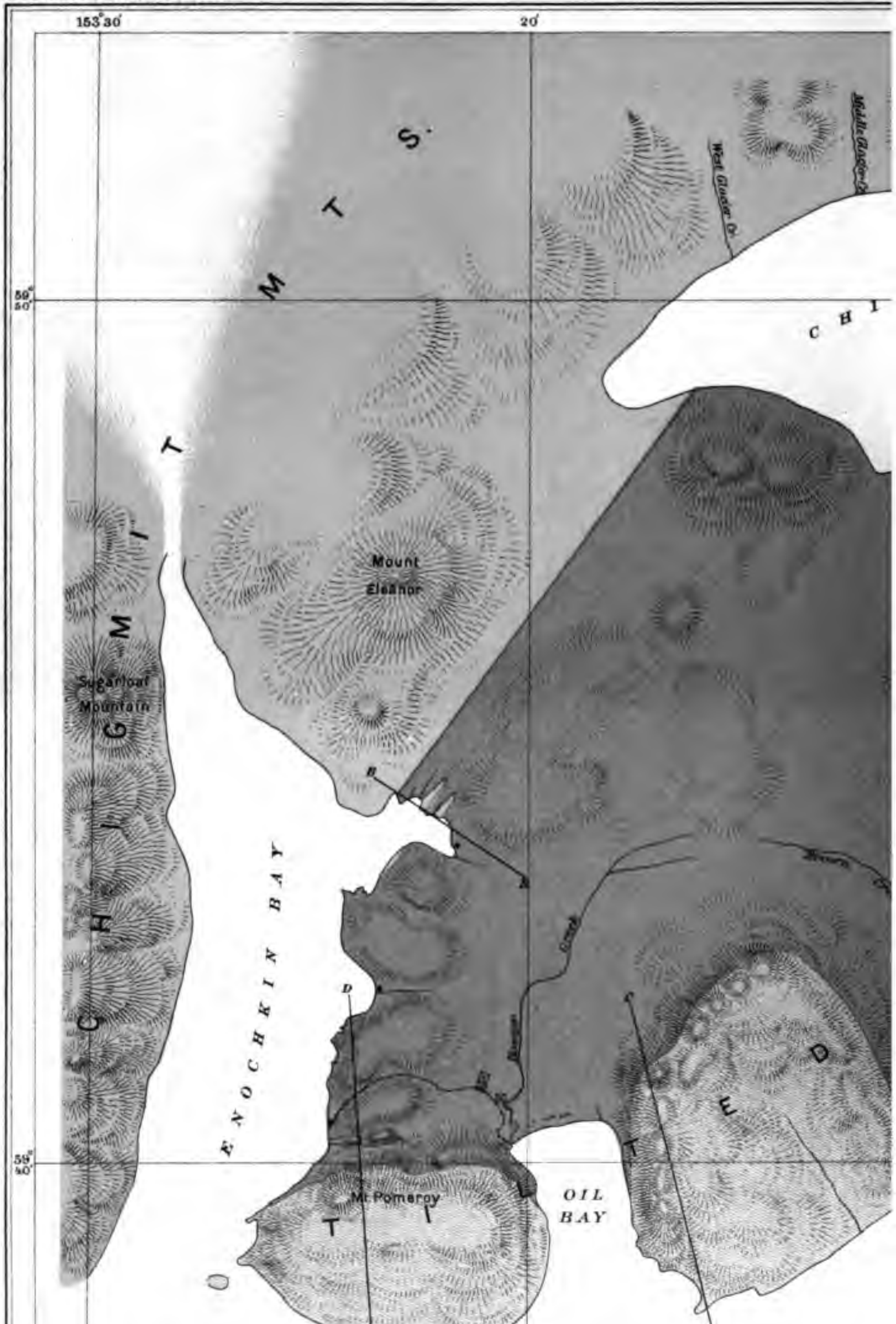
This route would have the advantage of a deep (though not very secure) harbor free from glacial drift ice, of distance, of a low grade from the harbor to the mines, and of the absence of bridges over large streams which are liable to severe floods.

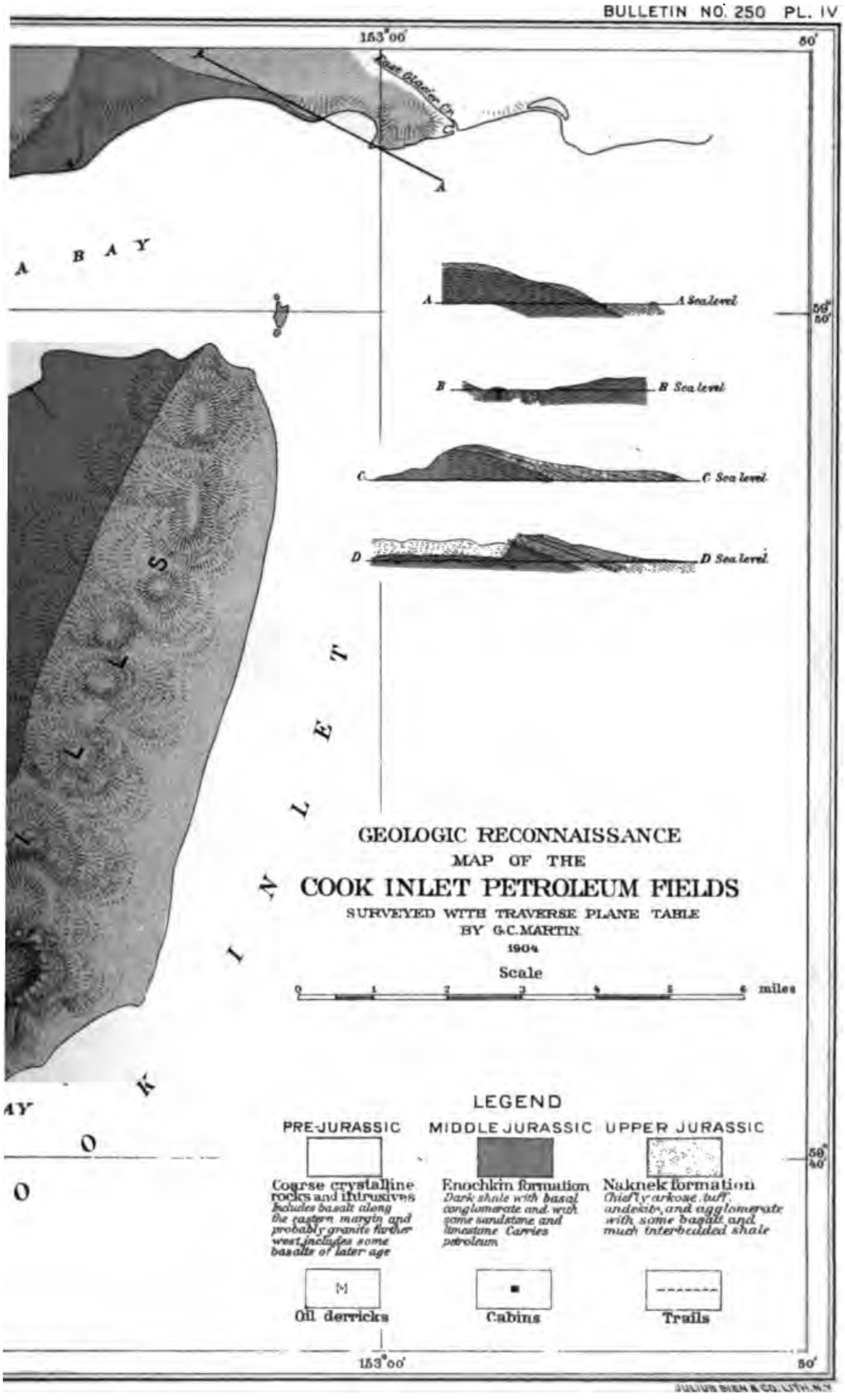
Another route would be from a long pier extending into Controller Bay from Point Hey over Kanak Island. This route would extend from Point Hey northwestward to Katalla River; thence up the east side of that river to Bering Lake, where it would join the route outlined above. It would be 1 to 2 miles longer than the first route. A third route would extend from a long pier on the eastern side of Controller Bay up the tidal flats east of Bering River, past the east end of Bering Lake and across Bering River above its entrance into the lake; from here branches could be built up the east side of Shepherd Creek and up the northern bank of Bering River on the extension of the first route. The length of this road would be 15 miles from the pier to the junction on the north bank of Bering River. The distances from this point to the coal openings on Carbon Creek, and to the mouth of Stillwater Creek, are 17 miles. This route would have the advantage of a more secure harbor than the first one, and also the advantage of a saving in distance. It would have the disadvantage of crossing Bering, Nitchawak, and other rivers, which are liable to severe floods every year, and the further disadvantage of having its harbor liable to be blocked with ice during some of the winter months.

Another possible route would extend from the eastern shore of Controller Bay northeastward until it reached the dead moraine of the Bering Glacier; thence northward along the moraine to the shore of Bering River at or near the mouth of Stillwater Creek. From this point branches could be built up Bering River to Canyon Creek, up Stillwater Creek to the coal openings on Trout Creek and Lake Kushtaka, and either from the lake to Carbon Creek or by an independent route down Bering River and up Shepherd Creek to Carbon Creek. This route would have the advantage of easy and cheap grading over the dead gravel moraine and of crossing the rivers nearer their sources by a larger number of small bridges rather than by a few large ones. It would have the disadvantage of being somewhat longer than the last route. The petroleum could be shipped from the same harbor as the coal, and as the petroleum belt is nearer the coast the problem of transportation prior to water shipment would not be a serious one. The wells which have been drilled up to the present time, and probably those which will be drilled in the immediate future, are near the coast, so that transportation to the piers could be effected by very short pipe lines. The prospective railroad to the coal mines would not at all be needed for the petroleum.

If a field should be developed on Nitchawak River or to the eastward in the Yaktag region a long pipe line would be necessary, and shipments would have to be effected either from the eastern shore of Controller Bay or the pipe line could be carried across Bering River. It is said a company owning claims in this region has made surveys for a pipe line from Controller Bay to Cape Yaktag, a distance of about 75 miles.

U. S. GEOLOGICAL SURVEY

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153°00'
50'
LEGEND
PRE-JURASSIC
Coarse crystalline rocks and intrusives
Includes basalt along the eastern margin and probably granite farther west, includes some basalts of later age
MIDDLE JURASSIC
Enochkin formation
Dark shale with basal conglomerate and with some sandstone and limestone Carries petroleum
UPPER JURASSIC
Naknek formation
Chiefly arkose, tuff, andesite, and agglomerate with some basalt and much interbedded shale
Oil derricks
Cabins
Trails
Scale
0
1
2
3
4
5
6 miles

GEOLOGIC RECONNAISSANCE
MAP OF THE
COOK INLET PETROLEUM FIELDS
SURVEYED WITH TRAVERSE PLANE TABLE
BY G.C.MARTIN
1904

JULIUS BIEN & CO. LITH. N.Y.

COOK INLET PETROLEUM FIELDS.

GEOGRAPHY.

The region under discussion occupies the western shore of Cook Inlet from the foreland on the north side of the entrance of Chinitna Bay, southwestward for about 40 miles, to the mouths of Enochkin[a] and Iliamna bays, and extends inland, with a maximum width of about 10 miles, to the crystalline rocks at the eastern front of the Chigmit Mountains. Its coast includes the deep indentations of Chinitna, Enochkin, and Iliamna bays, and the lesser ones of Oil and Dry bays (Pl. IV).

The region includes a high mountain range, a range of lower hills, and an intervening valley region. The rugged Chigmit Mountains have an average elevation of about 3,500 feet, and are parallel to the general shore of the inlet. The Tilted Hills from the mouth of Enochkin Bay northeastward to Snug Harbor run parallel to the coast at the distance of a mile, and have a general elevation of about 2,200 feet (Pl. V). An area of depression occupies the position between these two ranges, and consists of many valleys drained by streams flowing into the bays named above, and of irregular, low, rounded hills. The divides between the drainage systems are low and permit easy portages. The streams are all small, for the most part unnamed, and entirely unnavigable.

The lowlands are covered with dense vegetation and consist of about half meadow and half forest. The meadows are deeply grassed and are dotted with groves of cottonwood and thickets of alder and willow. The forests consist of a fair growth of spruce and hemlock, and though trees are not large, they are straight and sound.

A wagon road has been built from the lower landing point of Enochkin Bay to the head of Oil Bay, and there are cleared trails from the head of Oil Bay to Dry Bay, to the head of the eastern arm of Enochkin Bay, and to a point on the shore of Enochkin Bay 2 miles above the lower landing. There are also two trails from Dry Bay to the shores of Chinitna Bay, and a portage trail from the head of Enochkin Bay to the head of Chinitna Bay. (See Pl. IV.)

GEOLOGY.

The rocks of this region consist of a zone of massive crystallines, exposed in the Chigmit Mountains; a sedimentary formation of Jurassic age in a belt east of them, and a series of overlying agglomerates, shales, and bedded volcanic flows, which are exposed in the

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[a] This has been variously spelled as Inerskin, Innerskin, Inischen, and Innisken, but that here given is said to be the correct spelling of the Russian name.

Tilted Hills. The formations lie in belts parallel to the coast. The relation of the sedimentaries to the crystallines is complex and obscure, but the remainder of the series is conformable throughout (except for an unconformity between the Jurassic and the Tertiary) and is gently and simply folded. The general section is as follows:

General section of the Cook Inlet petroleum fields.

	Feet.
Tertiary:	
Sandstone, shale, and conglomerate with fossil trees and leaves	100?
Upper Jurassic:	
Naknek formation: Interbedded sediments and volcanic rocks (arkose, andesite, tuff, sandstone, and shale)	5,000
Agglomerate (best developed on Enochkin Bay)	300
Middle Jurassic:	
Enochkin formation (shale and sandstone with some conglomerate)	3,000?
Pre-Jurassic:	
Coarse crystalline rocks.	

PRE-JURASSIC CRYSTALLINES AND INTRUSIVES.

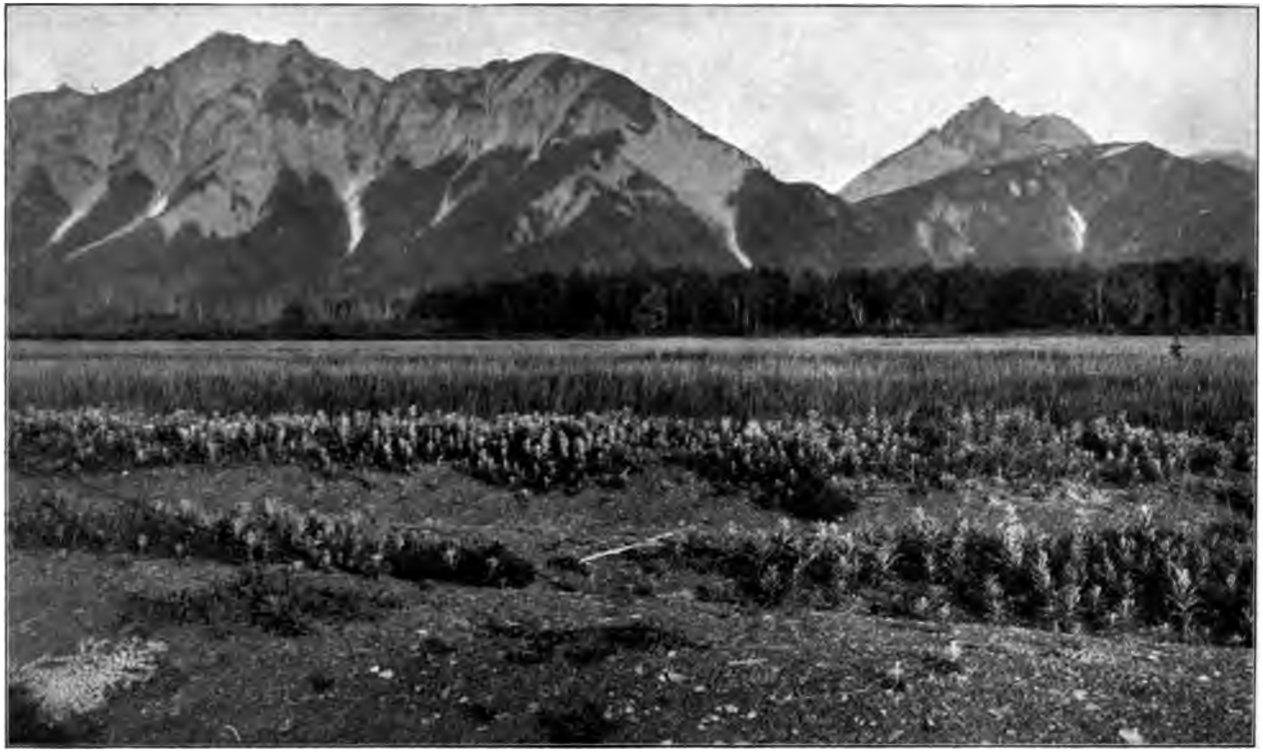
The crystalline rocks of the Chigmit Mountains extend along the entire western shore of Enochkin Bay and both shores of the northern arm of that bay. There is considerable variety in the series, but granite and rocks similar in texture and general appearance predominate.

The exposures along the eastern margin of this belt consist of basalts varying considerably in appearance. The eastern side of the point between the arms of Enochkin Bay contains good exposures of a reddish porphyritic rock. A greenish rock is exposed east of this on the northern shore of the eastern arm of the bay, and a rock of similar color and appearance is exposed on the north shore of Chinitna Bay. These rocks were shown by microscopic study to be of identical mineralogic composition, and were determined to be basalt.

The basalt may be either a member of the pre-Jurassic crystalline complex which forms the main mass of the Chigmit Mountains and the backbone of the Alaska Peninsula, or a post-Jurassic intrusive. The writer is inclined toward the former view.

MIDDLE JURASSIC ROCKS.

Enochkin formation.—The rocks overlying the crystallines consist of a thin conglomerate at the base, followed by more than 3,000 feet of dark sandy shales with occasional bands of sandstone, conglomerate, and limestone and many fossil beds; they are well exposed in the cliffs on the east shore of Enochkin Bay. Rocks of the same lithologic character extend along the strike northward from these exposures, passing the heads of Oil and Dry bays to Chinitna Bay. They have not been followed by the writer beyond the north shore of



LANDWARD FACE OF TILTED HILLS, CHINITNA BAY.

Enochkin formation overlain by Naknek formation.

Chinitna Bay, but from the great thickness exposed it is evident that they must extend thence a considerable distance. Rocks of similar lithologic character have been reported from the vicinity of Snug Harbor.[a] Fossils are distributed throughout the entire thickness of the formation, and show the age to be middle Jurassic.

A generalized section of the Enochkin formation is as follows:

Generalized section[b] of Enochkin formation.

	Feet.
Dark-drab shale with abundant limestone concretions and with numerous fossils (zone D)	1,283
Concealed	25
Sandy shale with many fossils (zone C)	50
Concealed	20
Shale with some sandstone	150
Conglomerate	10
Concealed	
Shale with several fossil bands (zone B)	50
Concealed	
Shale with one or more fossil bands (zone A)	30
Concealed	
Shale	12
Coarse conglomerate	20
	1,650+

The lowest bed is a basal conglomerate about 20 feet thick. The pebbles are large (averaging several inches in diameter) and were derived from crystalline rocks, principally granite. The shales at their very contact with the conglomerate are fossiliferous.

The point at the south side of the entrance to the eastern arm of Enochkin Bay[c] shows several outcrops of shale, with several beds abundantly filled with fossils, each bed being from 10 to 25 inches thick. About 30 feet of shale is exposed. The strata immediately above and below are concealed, and there are no good exposures between this point and the contact 1 mile northeast, described above, nor for a distance of 1 mile below it. At the latter point good exposures again begin and are continued along the shore for a distance of about 3 miles, the strata exposed in this interval being dark, sandy, fossiliferous shales. Fossils were collected from these zones, but were mixed in transportation, and it is consequently not possible to give the faunal lists separately. The specimens of the combined faunas have been submitted to Dr. T. W. Stanton, who determined the following species and assigned the faunas to the middle Jurassic.

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[a] These beds were traced as far north as Snug Harbor during the summer of 1904.

[b] The concealed intervals in this section are very large. The total thickness probably exceeds 3,000 feet.

[c] On this point are also large masses (not in place) of brown sandy shale; there are numerous bowlders of this rock, but no exposures in place. The bowlders are always near the basal contact of the Enochkin formation and can not have been transported far. The sandstones from which these probably came were seen during the summer of 1904 in the region to the northward.

Specimens from sandy fossiliferous shales, Enochkin Bay.

2919.—East shore of Enochkin Bay, Cook Inlet, above lower cabin, zones A and B in lower part of Enochkin formation.

Belemnites sp. Fragments.
Thracia sp.
Trigonia doroschini Eichwald. Abundant.
Trigonia sp. Belongs to Clavellatæ group.
Grammatodon? sp. a.
Pseudomonotis? sp.
Pecten sp. A single very small, smooth form.
Ostrea sp. Fragmentary specimens of a small irregular species.

A total thickness of the foregoing beds of probably 150 feet is exposed, and then the continuity is broken by a fault having a displacement of at least 25 feet, beyond which the following section is exposed:

Section of part of Enochkin formation.

	Feet.
Soft shale	20
Dark-drab shale with scattered fossils	33
Hard calcareous shale full of fossils, principally pelecypods	2
Black sand	1
Dark shale	5
Black sand	1
Dark shale with many fossils	12
Reddish limestone	½
Dark shale with many fossils	14
Dark shale with scattered fossils	62
Soft dark sandstone with streaks of conglomerate	10
	160½

A concealed interval of about 20 feet in thickness succeeds this section. Then there is an exposure of about 50 feet of fossiliferous shale, followed by another concealed interval of about 20 feet. A richly fossiliferous zone is exposed here, from which a representative collection was made. The following forms have been identified by Dr. T. W. Stanton, who considers the fauna to be of middle Jurassic age.

Specimens from richly fossiliferous shale, Enochkin Bay.

2090.—East shore Enochkin Bay, below and near lower cabin, zone C, about 800 feet above base of Enochkin formation.

Stephanoceras sp.
Belemnites sp. a.
Belemnites sp. b. Abundant.
Belemnites sp. c.
Grammatodon? sp. a.
Grammatodon? sp. b.
Inoceramus eximius Eichwald.[a] Abundant.
Pecten sp. Small form, same as in lot 2919.
Pecten sp. Large individual that may be adult of last named.

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[a] The forms described by Eichwald as *I. eximius*, *I. ambiguus*, and I. *porrectus* may all *belong to one species.*

Good exposures continue from this point to the mouth of the bay. This shows not only the upper part of the Enochkin shales but also much of the overlying strata. The upper part of the Enochkin formation as here exposed is as follows:

Section of upper part of Enochkin formation.

	Feet.
Dark-drab shale, with numerous bands of limestone concretions filled with well-preserved specimens of Cadoceras, Belemnites, etc., and with occasional sticks of fossilized wood	146
Concealed by talus at "Mushroom Rocks" (computed)	77
Dark shales, as above, with same concretions, wood, and fossils	190
Dark shales, as above, with Cadoceras	6
Limestone	1
Dark shales, as above, with fossils	68
Shales, as above	295
Concealed by talus (computed)	300
Shales, as above, with Cadoceras	200
	1,283

Fossils were collected from the entire thickness of these beds. Dr. T. W. Stanton has identified the following forms, which show relationship with the Callovian fauna occurring in Europe near the top of the middle Jurassic.

Fossils from upper part of Enochkin formation, Enochkin Bay.

2021.—East shore of Enochkin Bay for a mile below lower cabin, zone D, uppermost 1,200 feet of "Enochkin shales:"

Cadoceras doroschini (Eichwald). Abundant.
Cadoceras wosnessenskii (Grewingk).
Cadoceras schmidti Pompeckj.
Cadoceras catostoma Pompeckj?
Cadoceras sp.
Macrocephalites? sp.
Phylloceras subobtusiforme Pompeckj?
Stephanoceras sp. Form figured by Eichwald as Amm. astierianus d'Orb. aff.
Belemnites sp. a. One specimen.
Goniomya sp. One small specimen.
Lima sp.
Pecten sp. Small, smooth form.
Pleuromya? sp. One specimen.
Serpula? sp. Small discoidal form abundant in one rock fragment.
Several undetermined bivalves represented by imperfect material.

Compiled detailed section of the Enochkin formation.

	Feet.
Zone D:	
Dark-drab shale, with numerous bands of limestone concretions filled with well-preserved specimens of various cephalopods and belemnites and with occasional sticks of fossilized wood	146
Concealed by talus (all shale as above), thickness computed	77
Shales as above, with same concretions and wood	196
Limestone	1
Shales as above	363
Shales (partly concealed by talus), thickness computed	300
Shales as above	200
Concealed	25+
Zone C:	
Sandy shales with many fossils	50
Concealed	20
Soft shale	20
Dark-drab shale with scattered fossils	33
Hard calcareous shale full of fossils, principally pelecypods	2
Black sand	1
Dark shale	5
Black sand	1
Dark shale with many fossils	12
Reddish limestone	½
Dark shale with many fossils	14
Dark shale with scattered fossils	62
Dark soft sandstone with streaks of conglomerate	10
Concealed	
Zone B:	
Shale with several fossil bands	50
Concealed	
Zone A:	
Shale with one or more bands packed with fossils, each fossil bed 10 to 25 inches thick	30
Concealed	
Shale	12
Coarse conglomerate	20
Unconformity	
Greenish basalt	

The following section was measured at Oil Bay. It is the opinion of the writer that the lower 1,294 feet represent the upper part (zone D) of the Enochkin formation:

Section on north shore of Oil Bay.

Naknek formation:	
Arkose, andesite, sandstone, conglomerate, and shale	2,000
Sandy shale with Aucella near base	600
Shale with fossils	380
Coarse sandstone	3
Shale with fossils	165
Concealed	40
Sandstone and sandy shale with plant impressions	310
	3,498
Naknek formation?:	
Agglomerate with an abundance of small pebbles one-twelfth to one twenty-fifth inch in length, and with numerous poorly preserved plant impressions	7
Sandy shale and sandstone	85
Agglomerate with pebbles as above	3
Shale	1
Fine agglomerate of same pebbles as above	7
Fine agglomerate of same pebbles as above, but interbedded with shale	14
Olive shale[a] with an abundance of small pebbles as above	30
	147
Enochkin formation:	
Dark shale with concretions	690
Hard dark sandstone	½–¾
Dark-drab shale with numerous concretions	530
Calcareous shale with Cadoceras schmidti Pompeckj, Cadoceras, sp. cf. stenoloboide Pompeckj, and Phylloceras	1
Dark shale	60
Soft green sandstone	½
Dark-drab shale	12
	1,294

The cliffs on the north shore of Chinitna Bay expose a thickness of many hundred feet of the upper part of the Enochkin shales. Exact measurements were not made here, so it is impossible to tell what proportion of the formation remains below water level. The cliffs south of the bay, on the landward escarpment of the coast range, also show a thickness of many hundred feet of the same rocks. Neither section has been studied in detail.

Fossils are distributed throughout the entire thickness of the Enochkin formation, and show the age to be Jurassic. It consists of at least two well-marked paleontologic subdivisions. The lower 800 or 1,000 feet contain several faunules, in which the pelecypods predominate (zones A, B, and C), and which Dr. T. W. Stanton considers middle Jurassic. The upper 1,300 feet (zone D) are characterized by the abundance of large cephalopods, especially several species of *Cadoceras*, which, with the *Belemnites*, predominate over all other forms. Dr. Stanton places this fauna near the top of the middle Jurassic, it possibly being the equivalent of the Callovian. It is to be compared with the Jurassic rocks from Cold Bay described by Dr. W. H. Dall and also in this report, and with those described by Doctor Dall from Tuxedni Harbor (Snug Harbor), Kamishak Bay, and other localities on the Alaska Peninsula.

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[a] Indeterminate fragments of a crustacean, evidently not related to the one from Bering Lake (see p. 14), were collected 5 feet above the base of this.

UPPER JURASSIC ROCKS.

The Enochkin shales are overlain by a series of volcanic flows of andesite and basalt, and by coarse agglomerate, with much interbedded tuff, arkose, and shale. While the agglomerate seems to be confined to the shore of Enochkin Bay, the series as a whole forms the high coastal ridge which extends from Enochkin Bay to and beyond Chinitna Bay, the total thickness being probably more than 5,000 feet.

Agglomerate.—The Enochkin shales as exposed in the type section are overlain with apparent conformity by a bed of agglomerate having a computed thickness of 290 feet. The pebbles vary in size from less than an inch to 6 or 8 inches in diameter, are well rounded, and composed principally of granite, though occasional pebbles of some other crystalline or of schistose rocks are seen. The cement is evidently a volcanic ash of andesitic character.

The thick beds of coarse agglomerate have been seen by the writer only in the section described above, and it is probable that they are a local facies of the series of igneous flows which outcrop at the mouth of Chinitna Bay and along the shore of Cook Inlet, both north and south of that point. If such be the case, then the very fine tuffaceous agglomerate described in the Oil Bay section (see p. 43) is probably the equivalent of the coarser agglomerate exposed a few miles southwestward on Enochkin Bay.

Naknek formation.—In the section on the east shore of Enochkin Bay the bed of agglomerate is overlain by a series of very homogeneous, dark, sandy shales, with a computed thickness of 583 feet. No fossils were seen in these shales at their exposure on the shore of Enochkin Bay.

The shales are overlain by an alternating series of andesite flows and beds of agglomerate, the thickness exposed on the shore of Enochkin Bay being computed at 270 feet. Beyond the mouth of Enochkin Bay, in the cliffs on the shore of Cook Inlet, higher beds are exposed. The entire thickness is not known.

The Enochkin shale exposed on the shores of Chinitna Bay and in the Dry Bay and portions of the Oil Bay regions is overlain conformably by a series of arkose and other sediments interbedded with andesitic flows (fig. 3). These with their relation to the underlying shales are well exposed on the southern shore and near the mouth of Chinitna Bay. From this point, along Cook Inlet to Oil Bay, a continuous section of the series of flows is to be seen, the total thickness of which has not been measured, but is probably about 3,500 feet. The igneous rock is occasionally interbedded with shales, which in the cliffs between Oil Bay and Dry Bay contained *Belemnites*. They are thus shown to be of Mesozoic age. Probably the igneous rocks with their interbedded shales are to be referred to the upper Jurassic.[a] This series is certainly allied in age and is the equivalent of the Naknek formation which Spurr[b] described from the shores of Naknek Lake. It would appear from Spurr's description of this formation, as well as from the writer's observations, that it contains more arkosic material and less fine, well-assorted sediments than the shales of the Enochkin formation. Enough fossils have been collected from the Naknek formation to determine from paleontologic evidence the exact faunal equivalency. It seems best, therefore, in view of the lithologic similarity and the relations of the faunas, to use the same for the rocks exposed on the western shore of Cook Inlet.

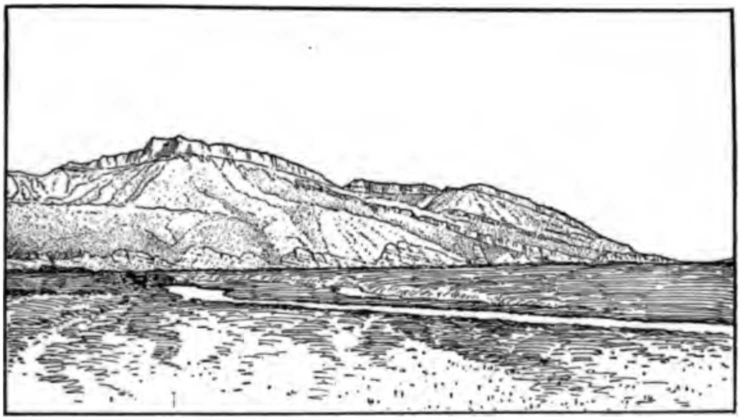

FIG. 3.—Enochkin formation, capped by Naknek formation, Oil Bay.

POST-JURASSIC ROCKS.

North of the mouth of Chinitna Bay is a belt of lowland which extends eastward for several miles. The shore consists of alternate bluffs and beaches, the latter thrown across the ends of swamps and one or two forming lagoons behind them. A number of the bluffs are rock cliffs (igneous rock, bedded, as on south shore of the bay), while the others are composed of angular fragments of the same rock. The more easterly ones are all of the latter kind.

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[a] Abundant fossils, including *Aucella* and other characteristic upper Jurassic forms, were collected from these beds during the summer of 1904. Doctor Stanton considers the evidence of these fossils sufficient both for the reference of these beds to the upper Jurassic and for correlation with the Naknek formation of the Alaska Peninsula region.

[b] Spurr, J. E., A reconnaissance of southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 169–171.

The most easterly of the rock cliffs shows the following section:

Section on north shore of Chinitna Bay.

	Feet.
Conglomerate with interbedded shale and sandstone, the last two carrying fossil sticks and fragmentary leaf impressions	15
Dark-gray shale, with upright tree trunks	20

The strata here are almost or quite horizontal. The trees are between 1 and 2 feet in diameter, are silicified, and show the structure of the wood very distinctly, while numerous small sticks lie in the bedding of the shale. The leaves are Tertiary species.

STRUCTURE.

The structure of this region consists of a broad, low, somewhat undulating anticline parallel to the shore of Cook Inlet and to the general line of the eastern front of the Chigmit Mountains, followed on the west by a narrow syncline, beyond which is a second very closely folded and probably faulted anticline. The dip in the broad easternmost anticline is moderate in amount and very regular, except on the crest of the fold, where it is undulating, but not in excess of 10°. On the eastern limb the dip varies from 20° to 28°, diminishing as the shore is approached, and on some of the long points and islands becoming almost or quite horizontal. The steepest dip in the southwestern part of the field was observed on the shore of Enochkin Bay, where the rocks are inclined southeastward at an angle of 28°. The greatest dip at the northern end of the field is between half a mile and a mile southeast of the entrance to Chinitna Bay, where it varies from 25° to 45° SE. On the western flank of this anticline the dip is about 17°.

The nature of the undulations at the crest can be seen in the cliffs on the eastern side of Enochkin Bay. The dip is southeastward for the first 4 miles above the mouth of the bay, measured along the shore, and averages about 20°. There is then a low anticline at the mouth of a small creek, 4 miles above the entrance to the bay and half a mile below the lower cabin, which is situated at the end of the wagon road to Oil Bay. A small syncline is crossed at the lower cabin or just below it. The dip is southeastward for about 2,000 feet along the shore above the cabin, where the rocks bend over the top of another low anticline and dip to the northwest. Just below this point a fault, with a displacement of at least 25 feet, extends into the cliff at right angles to the shore. The fault plane is perpendicular to the bedding, which dips 10° SE. A crevice 6 feet wide is opened along the fault plane. For about 3 miles north from this fault the strata undulate somewhat, but have a general dip to the northwest, which finally becomes very pronounced and is constant at an angle of from 15° to 17° for a distance of over a mile, thus forming the general western flank of the greater anticline.

The syncline which adjoins this anticline on the west is a much narrower and simpler fold. It is characterized by a steeper dip on the western than on the eastern flank. It appears to die out toward the northeast and was not recognized on Chinitna Bay. West of this syncline is an anticline in which the rocks are badly crumpled and faulted. The crystalline rocks are exposed on its western side and at places within it. The contact of the westernmost outcrops of the shales with the crystalline rocks appears to be along the line of a great fault.

The amount of pitch of the axes of these folds is not known.

The contact of the Enochkin formation with the underlying crystallines has been seen only on the east side of Enochkin Bay. The locality on the south shore of the northeast fork of the bay would seem to show that the formation rests unconformably upon the green porphyritic rock, though, on the other hand, the locality across the bay, on its northern shore, suggests that the green rock may be younger and intruded. Another hypothesis may also be considered, namely, that the Enochkin formation is unconformable upon the green rock and that the western line of outcrop of the former is along a zone of faulting which has thrown a block of the green rock into the dike-like position seen on the north shore. The crushed zone west of this locality favors this hypothesis, as does also the fact that on Chinitna Bay, some distance northeast of this point, the contact of the Enochkin formation with the green rock has transgressed eastward across the series of folds in the former, so that there is only one anticline instead of two, as on Enochkin Bay. This hypothesis is favored also by the occurrence of abundant fragments of brown, sandy, shale or shaly sandstone along the western border of the belt occupied by the Enochkin formation.

OCCURRENCE OF PETROLEUM.

Surface indications.—The surface indications of petroleum in this region consist of seepages or oil springs and the so-called "gas springs." In the first, the petroleum may be seen oozing from the cracks in the rock or coming out of the soil. On the east shore of Enochkin Bay a good seepage was seen about 1,000 feet below the lower cabin, although the spring is covered at high tide. The flow is often so strong that the petroleum collects in large blotches on the pool, or even covers its entire surface. At one point it issues from a crevice in the shale of the Enochkin formation.

In the vicinity of the cabin at Oil Bay are a number of large springs. From the bottom of one the petroleum is almost continually rising, the flow varying, however, from time to time, now almost ceasing, now becoming very strong. It is frequently possible to skim several quarts of petroleum from the surface of the pool.

About 2 miles west of the beach at Dry Bay is a so-called "gas spring," gas of unknown composition rising in a continuous stream of bubbles to the surface of the water. From the north shore of Chinitna Bay both oil and gas springs have been reported, but they were not seen by the writer.

The geologic structure of this region has already been outlined. It consists of a long anticline bending from an east-west direction at the southern end to a northeast-southwest direction at the northern end, and so keeping parallel to the coast. The dip on each flank is regular and comparatively moderate, seldom exceeding 20°. Although in the actual region of the fold the strata are faintly undulating, the crown of the arc is almost flat. Other things being equal, the fold is such, indeed, as should yield a good flow over a considerable area, granting the existence below of a porous reservoir capped by impervious beds and filled with oil. The center of the zone, which at the present seems to be the most promising, lies on a line extending from a point about a mile above the lower cabin on the shore of Enochkin Bay to a point a half mile northwest of the beach at Oil Bay, thence through a third point 2 miles above the beach at Dry Bay to the center of the high cliff on the north shore of Chinitna Bay. The oil sand would probably be found nearer the surface along this line than either to the southeast or the northwest.

As in all cases, however, drilling is necessary to obtain a knowledge of the underground conditions, as well as to estimate the economic and commercial value of the field. Thus far this has been insufficient. As regards the entire Enochkin Bay region, it is almost certain that the oil will be confined to the easternmost anticline.

Development.—Indications of petroleum were discovered in this region about fifty years ago. The first was taken out in 1882 by a Russian named Paveloff. A Mr. Edelman staked ground in 1892. His location was near the divide at the head of the creeks entering Oil and Dry bays, but the claims were subsequently abandoned. In 1896 Pomeroy and Griffen also staked property at Oil Bay, and during the next year organized the Alaska Petroleum Company. Work was begun in 1898. The Alaska Oil Company was organized in 1901, and in 1902 began drilling at Dry Bay.

The first well at Oil Bay was begun in 1898 and has been drilled to a depth of somewhat over 1,000 feet. No log of this well or any very authentic information can be obtained, as the property has changed management several times. It is reported that gas was encountered all the way below 190 feet, and that considerable oil was found at a depth of 700 feet. The flow of oil is reported as having been estimated at 50 barrels. On drilling deeper a strong water pressure was encountered, which shut off the flow of oil. The well is now over 1,000 feet in depth and affords a continuous flow of gas, which at times becomes very strong. Attempts have been made to shut off the flow of water and either recover the lost oil or drill deeper, but without success.

A second well, located about a quarter of a mile west of the older one at Oil Bay, was drilled during the summer of 1904.

Record of well at Oil Bay, as reported by Mr. August Bowser.

	Feet.
Sandstone	200
Shale	120
Oil and some gas	1
Shale (caving)	129
Total	450

The well was abandoned at a depth of 450 feet because the shale caved so badly.

A third well located about 250 feet south of the last was also drilled during the summer of 1904.

The general sequence of strata was the same as in the last well, the shale continuing to the bottom of the hole. The well was cased to a depth of 630 feet. Oil and gas were encountered at a depth of 770 feet, there being three small oil sands, each 6 to 8 inches thick and 4 or 5 feet apart. The well was estimated at 10 barrels. The caving rock was encountered at 830 feet. Work was stopped at a depth of 900 feet at the end of the season. Considerable gas was encountered at various depths, at times the pressure being strong enough to blow the water up in the derrick to a height of 20 feet.

A well at Dry Bay was drilled to a depth of 320 feet in the summer of 1902 without encountering oil. The tools were then lost and the hole was abandoned. In August, 1903, a new well was started in close proximity to the first, but not much was accomplished, and work was discontinued a few months later because of an accident to the machinery. Nothing has been done during the past season.

The shipment of petroleum from this field would probably be from Enochkin and Chinitna bays, which are harbors affording safe anchorage to large vessels in all weather, as well as good wharf sites. Ships can, however, anchor in the mouth of Oil Bay and off Dry Bay except during very bad weather. If the docks should be built either at Enochkin or Chinitna, it would be necessary to build pipe lines and pumping stations to transfer the product from the field to the shipping point. This would not, however, be a serious matter, as divides are low and construction and operation would be easy.

COLD BAY PETROLEUM FIELD.

GEOGRAPHY.

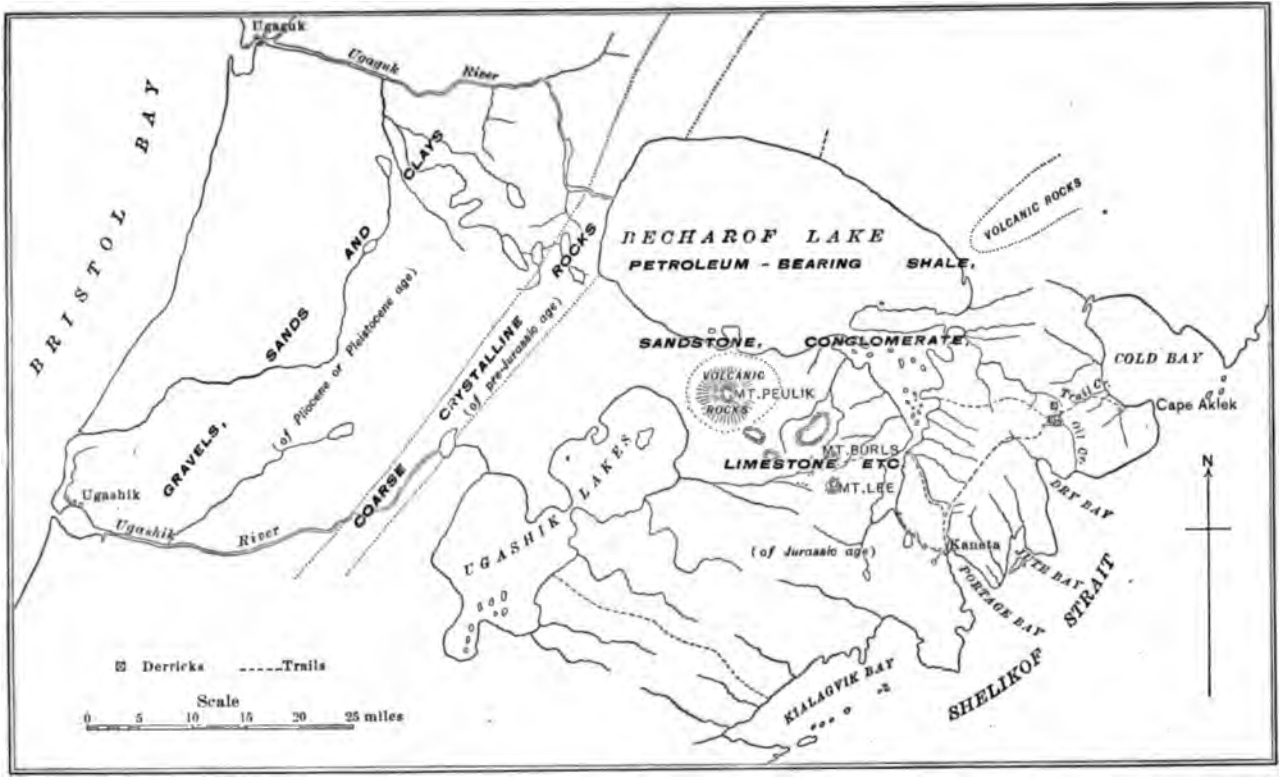
Cold Bay is situated on the south shore of the Alaska Peninsula. at the southwest end of Shelikof Strait and opposite the west end of Kodiak Island. (See map, Pl. I.) It may be reached by steamer from Seattle either direct or by transfer at Valdes or Kodiak, or from Dutch Harbor. From Seattle the time is about fifteen days; from Valdes, four. It may also be reached from Bristol Bay by a canoe and portage route across the peninsula.

The southern shore of the Alaska Peninsula is very sinuous, with deep indentations and long rugged forelands. Cold Bay, one of the best of the harbors, is roughly triangular in shape, about 10 miles long by 7 miles wide at the mouth, and contains a very large area of deep water. (See map, Pl. VI.) The surrounding country consists of an elevated upland with gently rounded or flat-topped hills rising above it, and its general level is about 750 feet above tide. The higher peaks rise to an elevation of about 1,500 feet, but farther back from the coast, in the central part of the peninsula, are mountains 5,000 feet or more in height. Among these is the volcano Peulik (about 5,000 feet), situated on the western shore of the southern arm of Becharof Lake, about 35 miles west of Cold Bay. This is one of the chain of volcanoes which extends the entire length of the Alaska Peninsula and the Aleutian Islands.

The streams emptying into Cold Bay and into the other bays in the vicinity are short and swift, carrying no very large amount of water. It is a striking fact that in this part of the peninsula the divide between the Pacific drainage and the Bering Sea drainage is situated in close proximity to the southern shore. For example, near Cold Bay, where the peninsula has a total width of about 90 miles, the divide is nowhere more than 10 miles from the southern shore, and is, in some cases, within a mile or two of the heads of the bays. These short, swift streams are characteristic of the entire southern slope of the peninsula.

The northern slope of the peninsula, on the other hand, is drained by a comparatively small number of fairly large rivers, which empty either into shallow bays or directly into the sea. All of these rivers have lakes at their headwaters or along their courses. Lake Becharof, the head of which is situated about 15 miles from the landing at Cold Bay, is one of the largest. The presence of such lakes and rivers throughout almost the entire area of the peninsula makes navigation in canoes or other small boats very easy, and almost all travel is accomplished in this way.

Timber is entirely lacking in this region, the only trees being a few small cottonwoods, willows, and scrub alders along the banks of the



SKETCH MAP OF COLD BAY PETROLEUM FIELD.

streams. The flat lowlands along the shores of Cold Bay are covered with deep grass, but the hillsides and upland region have no vegetation except scattered tufts of grass and moss (Pl. VII). This vegetation is characteristic of the greater part of the Alaska Peninsula.

There are no natives in the immediate vicinity of Cold Bay. The two oil companies which are operating in the region have brought their native employees from settlements at various points along the shores of Shelikof Strait.

GEOLOGY.

The region in the vicinity of Cold Bay has been visited by many geologists from time to time and a good deal of scattered information is published.

On one end of the promontory at the eastern entrance to Cold Bay Pinart obtained a number of specimens of *Monotis salinaria*, which was subsequently identified and figured by Fischer, and which is a characteristic Triassic form.

The promontory at the southwestern entrance to Cold Bay, which has been called by many names, but is now known as Cape Aklek, was visited by Doroschin, who collected *Belemnites*. Plant impressions which resemble and have been considered *Calamites*, but which have been shown to be reeds of a more modern type, occurred in sandstones just above.

The region was visited in 1895 by Dr. W. H. Dall, who says of it:

> Though no strata evidently of Kenai age were found in this bay, yet there were in several places fossil wood and vegetable remains. Near the northeast part of the harbor, east of a stream which comes in here, the rocks consist chiefly of calcareous sandstones, or sandy limestones, containing numerous concretionary nodules and some pebbles. In this nearly horizontal limestone, which is very massive and weathers into most bizarre shapes near the shore, we found a small seam of carbonaceous shale with occasional thin laminæ of clear coal. This shale is only a few inches thick. In shaly streaks of the limestone were vegetable impressions resembling those noted at Cape Douglas. On the other side of the stream, above the anchorage, these strata were arched and dipped 30° NW. On the opposite side of the main bay, well up on the hillside, was found a calcareous shale with impressions of pine needles, above which was a heavy bed of conglomerate covered by a hard, perhaps andesitic, rock of igneous origin. From fragments fallen from above it seemed that this rock is more coarse grained and friable higher up. It is unconformable with the other rocks. In the limestones near the south point of entrance impressions of reedlike plants and much fossil wood were observed. No coal seams were observed in this vicinity.[a]

Well up on the northeastern side of the bay is a valley which a stream drains, off the mouth of which is anchorage. Westward of the stream is a rather high (2,000–2,500 feet) ridge, recalling the Mesozoic mountains about Tuxedni Harbor, eroded in benches and having a singularly artificial aspect. From the first bench on this ridge Mr. Purington obtained a few Mesozoic fossils,

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[a] Dall, W. H., Report on coal and lignites of Alaska: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 1, p. 801.

> the most noticeable of which was a Rhynchonella, and a few others were obtained at high-water mark where the same ridge came down to the beach. The matrix was coarse and friable and the specimens were few, but it seemed certain that the two lots belonged to the same fauna, which must range through at least 1,000 feet of strata. The rock is chiefly a calcareous shale, barren of fossils, which disintegrates into small angular fragments, forming enormous and extremely regular talus slopes. Where a seam of sand and gravel or coarse sandstones is interleaved with the shales, there the fossils are found, but these seams are rare.[a]

The rocks seen by the writer in the vicinity of Cold Bay consist of dark-brown arkosic sandstone alternating with conglomerates, and a few thin limestones and dark shales which break on the weathered surface with a conchoidal fracture.

Fossils were collected at several localities. The low sandstone cliffs extending for about 1 mile above the store at the lower landing carry abundant specimens of *Belemnites*. Dr. T. W. Stanton has examined the specimens and is of the opinion that three species, indicating a horizon in the middle Jurassic, are present. He compares them with the faunas of the middle and upper zones of the Enochkin formation of the Cook Inlet region. Fragments of a small belemnite were collected at the base of the cliffs 2 miles northwest of Cape Aklek. Doctor Stanton considers that the horizon of this is Jurassic, but the fossils are too scanty and fragmentary for precise reference of the strata. The rocks at this point consist of arkosic sandstones well exposed in high cliffs. An ammonite was seen in the face of the cliff near the top, showing that the entire series is Mesozoic. Four miles southwest of this point, where Oil Creek flows into Dry Bay, specimens of *Cadoceras schmidti* Pompeckj were obtained. Doctor Stanton believes these fossils belong at the same horizon as those already referred to from the shores of Cold Bay.

General section in the Cold Bay–Becharof Lake region.

Name of formation.	Age.	Lithologic character.	Thickness.
	Post-Jurassic	Volcanic rock, probably andesite or basalt.	
Naknek formation.	Upper Jurassic	Arkose, conglomerate, sandstone, and shale.	3,000 to 5,000 feet.
Enochkin formation.	Middle Jurassic	Shale, sandstone, and a little limestone.	2,000 feet.
	Triassic	Shale, limestone, and chert.	
	Pre-Jurassic	Granite, syenite, etc.	

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[a] Op. cit., p. 870.

A

B

OIL DERRICKS AT COLD BAY.

The coarse crystalline rocks (granite, syenite, and rocks of similar texture) occur in a belt parallel to the length of the Alaska Peninsula. They cross the lower end of Becharof and Naknek lakes and possibly underlie the Cold Bay region.

The Triassic rocks occur on Cape Kekurnoi at the eastern entrance to Cold Bay, and on some of the capes and islands to the northeastward. They doubtless underlie the Jurassic throughout the Cold Bay region.

The Enochkin formation occupies both shores of Cold Bay, except at the northeastern promontory (Cape Kekurnoi) and at the head of the bay. It also extends in a belt along the shore of Shelikof Strait from Cold Bay to Dry Bay and probably as far beyond as Portage Bay.

The Naknek formation forms the shore of the head of Cold Bay and occupies the entire interior region as far west as Becharof Lake and as far north as Katmai.

The following section was measured on the east side of Rex Creek about 1 mile above the head of Dry Bay:

Section on Rex Creek, Cold Bay region.

	Feet.
Naknek formation:	
Arkose, sandstone, and shale	600+
Enochkin formation:	
Shale and sandstone	500
Sandstone	90
Argillaceous shale	400
Sandstone, shale, and conglomerate	300

The post-Jurassic volcanic rocks occur in a discontinuous belt near the center of the peninsula. This belt includes several volcanoes which have been active in comparatively recent time. The lavas are probably all either andesite or basalt.

It may thus be seen both from the previous observations quoted above and from the work of the writer that the rocks exposed in the immediate vicinity of Cold Bay are entirely Mesozoic. They carry Jurassic fossils everywhere except at the promontory on the east side of the bay, where Triassic fossils have been found.

Mount Peulik, the high peak on the southern shore of Becharof Lake, is a volcano that has probably been active in comparatively recent times. It is one of the many volcanic mountains which extend along the central axis of the Alaska Peninsula, and has apparently broken through the Jurassic sediments. Other similar mountains extend in a northeasterly direction from the north shore of Becharof Lake to and beyond the head of Naknek Lake.

Glacial deposits are probably entirely lacking in this region, except as they are reported in the moraines of small living glaciers on the higher mountains.

STRUCTURE.

The rocks in the vicinity of Cold Bay are very gently folded. The dips are low over wide areas and the zones of steep dip are narrow and infrequent.

It has been stated that there is a great anticline seaward, parallel to the southern coast, that has its axis near the ends of the forelands. This view is sustained by the fact that on at least one of these promontories rocks older than the Jurassic are exposed, but the writer has not seen any evidence which would show how far seaward the southeast dip may extend. This fold extends from Katmai to the cape at the east entrance to Cold Bay. No land extends far enough seaward below Cold Bay to reach the axis of this fold. The strike and the direction of the axis average about N. 45 E. The northwest dip seldom exceeds 6° on the forelands. It is considerably steeper on the east shore of Cold Bay.

There is a syncline parallel to this and northwest of it which extends from near the mouth of Dry Bay along the west shore of Cold Bay to the high bluffs above the mouth of Teresa Creek. At this point it is cut off by a fault which crosses the head of the bay and extends up the valley of Dry Creek.

A long anticline is exposed in the hills southwest of the bay, the axis reaching the shore a short distance from Portage Bay and extending thence inland in a general northeast direction. The maximum dips observed on the southern flank of this fold were about 2° to 10°; on the northern, 12° to 16°. Strikes of N. 2° E. and N. 10° E., respectively, were noted. The steeper dips were apparently confined to a narrow zone, beyond which a dip of 8° continued for a considerable distance. These observations of the writer show a structure corresponding to that which has been reported from the region of Portage Bay, where an anticline with a northeast axis is said to parallel the south arm of the lake in such a position that, if continued to the location of the oil derricks west of the shore of Cold Bay, it would coincide with the anticline seen by the writer and described above. The rocks exposed in the immediate vicinity of the oil derricks lie almost or quite horizontal. The dip in the hills south of the derricks is southwest at a low angle, while in the hills north of the derricks it is northerly at an average angle of 8°. According to report, the northwest dip is reversed near the center of the peninsula, so that part of Becharof Lake lies in a syncline, while near its northwestern shore a sharp anticline is said to rise, which brings to the surface not only the entire sedimentary series, but also a mass of crystalline rocks that form the core of the peninsula throughout most of its length.

It may be seen from the descriptions given above that the most striking structural features are an anticline with a northeast-southwest axis extending from a point 3½ miles above the mouth of Oil Creek to Kanata, and a syncline extending from near the mouth of Oil Creek northeastward into Cold Bay. The northern end of this syncline is cut off by a fault which extends up the valley of Dry Creek. The anticline terminates by flattening out.

The dips are quite uniformly northwestward on the north shore of Cold Bay and on the north side of Dry Creek. Along the southeastern side of Becharof Lake it is northwestward and westward. On the western shore of Cold Bay it is northwestward or horizontal. On Dry Bay it is southeastward. The dips seldom exceed 15° except toward the mouth of the bay, and are quite low and regular over wide areas. The region between Becharof Lake and the Becharof-Cold Bay divide has a uniform westward and northwestward dip.

INDICATIONS OF PETROLEUM.

Seepages.—There are several seepages at the north end of the anticline near the oil wells. In all of these the flow of petroleum is large and constant. One of them furnishes lubricating oil for use at the wells. There is also a considerable flow of gas at one of these seepages. Other seepages not seen by the writer are reported from various places along the crest of this same fold, near the head of Dry Bay and elsewhere between that point and Kanata. There is said to be even more important seepages on the west shore of the south arm of Becharof Lake.

Developments.—Three wells were begun in the summer of 1903. They are located about 5 miles from the landing on the west shore of Cold Bay, at an elevation of about 750 feet above tide, and are distant about 9 miles in an air line from Becharof Lake. (Pl. VII.)

One of the wells begun during the summer of 1903 was abandoned in the autumn at a depth of several hundred feet, and the derrick was moved to a new site a few hundred feet distant. Very little drilling had been done at this point up to the time the writer left Alaska.

The second well, mentioned in an earlier publication,[a] was drilled to a depth of about 1,400 feet. The drill is said to have penetrated several strata filled with thick residual oil having about the consistency of warm pitch. This well was finally abandoned during the summer of 1904, because of the strong continual flow of fresh water. It is now certain that this well is situated near a fault, which fact would seem to explain the presence of a large amount of fresh water at all depths and also the absence of the more volatile and fluid constituents in the oil. The machinery from this well has now been moved to a new location about 2¼ miles southeastward on Trail Creek. At last reports it had reached a depth of 1,500 feet.

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[a] Bull. U. S. Geol. Survey No. 225, 1904, p. 381.

Record of well at Cold Bay.

	Feet.
Sandstone	76
Hard sand with crevices	39
Sand with hard streaks	85
Oil sand, not hard	40
Sandstone with hard streaks	60
Oil sand, soft	8
Sandstone with hard streaks	82
Oil sand	25
Soft argillaceous sandstone	15
Soft blue sandstone with oil	5
	435

If petroleum is stored within the series of rocks about Cold Bay, other things being equal, the very gentle folding which the strata have undergone should be favorable to the formation of large pools. It is impossible, however, to tell at present how far the influence of the volcanic belt and faults may extend.

The petroleum from this field has a paraffin base and is probably similar to the Controller Bay petroleum. (See p. 58.) If petroleum should be discovered in commercial quantities in this region it can be piped from the wells to Cold Bay by gravity and shipped thence to San Francisco or to Puget Sound ports.

PETROLEUM RESIDUE.

On some of the hillsides near the oil derricks 5 miles inland from Cold Bay are seepages of petroleum that are in some cases continuous, in others intermittent. The petroleum runs down the hillsides in the watercourses, collecting at the bottom in peat bogs. Losing enough of its volatile constituents by evaporation to render it immobile, it remains there, impregnating the peat and forming over its surface a thick coating of black paraffin wax.

These deposits have already been of considerable importance in the development of the region, for the peat, impregnated with the paraffin wax, has proved a fuel of the greatest value, replacing even the coal from the mines of Puget Sound, which is imported in large amount for use under the boilers in drilling operations. The deposit which has furnished this fuel for the past season has an area of about 1½ acres. The material has been dug to a depth of about 3 feet without, in some cases, reaching bottom. This deposit alone contains enough of the residue to supply all local needs for fuel for some time to come. Another deposit has, however, been discovered in the vicinity, which has an area of 3 acres and a thickness of at least 10 feet. Many more also will doubtless be brought to light.

Chemical and calorimetric tests of petroleum residue have been made by Penniman & Browne, of Baltimore. The result of their tests is as follows:

Chemical and calorimetric tests of petroleum residue.

	Per cent.
Moisture	None.
Volatile matter	85.40
Fixed carbon	7.76
Ash	6.84
Total	100.00
Sulphur	.36
Soluble in gasoline	68.20
Calories	8,193

The table shows a material that compares favorably with most of the coals sold on the Pacific coast. It is, indeed, their superior as regards calorific power, ash, and amount of sulphur. The amount indicated in the table as soluble in gasoline represents the petroleum residue present, the remaining 31.80 per cent consisting of peat and earthy material.

PROPERTIES OF THE ALASKA PETROLEUM.

Controller Bay petroleum.—A sample of the petroleum from the well near Katalla has been tested by Penniman & Browne, of Baltimore, with the following results:

Test of petroleum from Katalla.

Specific gravity	(0.828 at 15.5° C.) 39.1° B
Distillation by Engler's method:	
Benzine (80°-150° C.)	21%, 54.9° B. (0.7573)
Burning oil (150°-300° C.)	51%, 40.6° B. (0.8204)
Residium (paraffin base)	28%, 23.9° B. (0.9096)
Sulphur	Trace

The burning oil was purified by concentrated sulphuric acid and soda, the volume of acid used up being too small to measure. The purified burning oil was put into a small lamp, where it burned dry without incrusting the wick or corroding the burner, and without any marked diminution of flame. The burning oil compares very favorably in these respects with Pennsylvania oil prepared in the same way.

The following analysis of this petroleum was published by Mr. Oliphant:[a]

Analyis of petroleum from Katalla Bay well.

Specific gravity at 60° F., 0.7958, equal to 45.9° Baumé.

Cold test did not chill at 3° F. below zero.

	Per cent.
Distillation below 150° C., naphtha	38.5
150° to 285° C., illuminating petroleum	31
Above 285° C., lubricating petroleum	21.5
Residue, coke and loss	9
Total	100

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[a] The production of pretroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

The results of the tests may be compared with those of other petroleums in the following table:

Tests of petroleum from Alaska and other fields.

	Alaska.[a]	Alaska.[b]	Pennsylvania.[c]	Ohio.[d]	Colorado.[e]	Mexico.[f]	Beaumont, Tex.[g]
Benzine (80°–150° C.)	21	38.5	16.5	10	16	10	2.5
Burning oil (150°–300° C.)	51	[h]31	54	50	40	60	40
Residuum	28	[h]30.5	29	40	44	30	57.5
Sulphur	Trace.	....	....	....	....	....	1.7
Gravity	39.1° B.	45.9° B.	....	....	43° B.	....	22°B.

[a] Penniman & Browne for this report.

[b] Oliphant, F. H., The production of petroleum in 1902: Mineral Resources U. S. for 1902, U. S. Geol. Survey, 1903, p. 583.

[c] Peckham, S. F., Report on Petroleum, p. 365.

[d] Woodman, Durand, Jour. Am. Chem. Soc., vol. 13, p. 168.

[e] Oliphant, F. H., Petroleum: Mineral Resources U. S. for 1901, U. S. Geol. Survey, 1902, p. 560.

[f] Stillman, T. B., Engineering Chemistry, p. 364.

[g] Hayes and Kennedy, Oil fields of Texas-Louisiana coastal plain: Bull. U. S. Geol. Survey No. 212, 1903, pp. 146–151.

[h] See above (p. 57).

The petroleum is clearly a refining oil of the same general nature as the Pennsylvania petroleum. It resembles the latter in having a high proportion of the more volatile compounds and a paraffin base and in containing almost no sulphur. The proportions of the several constituents given in the table above do not necessarily represent the full amounts that could be obtained in practice by different treatment.

Oil Bay and Cold Bay seepages.—Samples of the seepage petroleum from Oil Bay and Cold Bay have been collected by the writer. They were obtained by skimming the petroleum from the surface of the pools of water where it was continually rising from the bottom of the pool. An effort was made to obtain as much of the fresher oil as possible. Vegetable and earthy impurities were removed by straining through coarse cloth. Water could not be entirely removed. Oil for lubricating purposes at the neighboring wells is obtained from these pools in this manner.

The fresher oil is dark green. That which has remained on the surface of the pool for some time is dark brown.

The oil has doubtless lost a large part of its volatile constituents. The analyses therefore do not represent the composition which could be expected of the live oil from wells in this region. Such oil would have a lower specific gravity, higher percentage of the more volatile constituents, and lower percentage of the less volatile constituents, residue and sulphur. It would certainly be better than these samples in all respects, and would resemble them in having a paraffin base. It might not be of so high quality as the Controller Bay petroleum, but nevertheless it would be a refining oil.

The samples were submitted to Penniman & Browne, of Baltimore, who return the following report on their tests.

Tests of samples of seepage petroleum from Oil Bay and Cold Bay.

	Oil Bay.	Cold Bay.
Specific gravity at 60° F	0.9557 (16.5° B)	0.9547 (16.6° B)
Distillation by Engler's method:		
Initial boiling point	230° C	225° C.
Burning oil (distillation up to 300° C., under atmospheric pressure)	13.2% (29.5° B)	13.3% (29.6° B)
Lubricating oils (spindle oils) (120 mm. pressure, up to 300° C.)	39.2% (22.6° B)	28.3% (23.8° B)
Lubricating oils (120 mm. pressure, 300° C.–350° C.)	19.6% (17.9° B)	18.3% (18° B)
Paraffin oils (by destructive distillation under atmospheric pressure)	22.4% (20.4° B)	32.0% (20.4° B)
Coke and loss	5.6%	8.1%
Total sulphur	0.098%	0.116%

The distillation of the lubricating oils under diminished pressure, corresponding to refinery practice, was carried on until signs of decomposition set in. The resulting residue was unsuitable for making cylinder stock, and was therefore distilled for paraffin oils. These paraffin oils contain a considerable quantity of solid paraffin. It was not practicable to determine the amount of the material with the small amount of oil at our disposal.

The iodine absorption of the oils and distillates has been determined by Hanus's method (solution standing four hours), and is here tabulated:

	Oil Bay.	Cold Bay.
Burning oil	17.8% iodine	17.2% iodine
Lubricating oil	26.2% iodine	27.2% iodine
Heavy lubricating oil	35.8% iodine	35.2% iodine

These iodine numbers upon the lubricating oils were obtained upon the samples. For comparison, samples of similar oils were obtained from the Standard Oil Company, and the iodine numbers determined as follows:

Light distilled lubricating oil (spindle oil)	32% iodine
Dark lubricating oil (engine oil)	45.4% iodine

The burning oils were tested in a small lamp and found to give a good flame. All the oil was consumed without incrusting the wick or corroding the burner.

The sample of crude oil from Cold Bay was distilled in such a way as to give the maximum yield of burning oil; under these conditions 52.2 per cent of fair quality burning oil was obtained.

The oils are entirely similar; both have paraffin bases, and the products of distillation are "sweet." We are informed that these samples are "seepage oils." If a sufficient yield can be obtained by drilling, a very suitable oil for refinery purposes may be expected, containing a very much larger quantity of the more desirable lighter products.

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[Bulletin No. 250.]

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Bulletin No. 251

Series { A, Economic Geology, 44
B, Descriptive Geology, 55

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE GOLD PLACERS OF THE FORTYMILE, BIRCH CREEK, AND FAIRBANKS REGIONS, ALASKA

BY

LOUIS M. PRINDLE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., June 28, 1904.

Sir: I have the honor to submit herewith the manuscript and illustrations of a report entitled "The Gold Placers of the Fortymile, Birch Creek, and Fairbanks Regions, Alaska," and to recommend its publication as a bulletin.

This report contains the economic results of a reconnaissance of these gold fields of the Yukon basin which was carried out by Mr. Louis M. Prindle last season (1903). It has been prepared essentially for the placer miner and prospector, for which reason the descriptions of the auriferous gravels are presented in considerable detail, while only the salient features of the geology are treated. This course was determined upon because, although there was an immediate demand on the part of the mining public for information in regard to the gold placers, the geology is so complex that it will require several more field seasons to solve even the general problems of structure and succession.

Although the Fortymile and Birch Creek districts are among the oldest of the gold-placer producers of Alaska, Mr. Prindle's investigations show that they are by no means exhausted, and that, with the introduction of improved methods of mining, they will continue to yield good returns. It is too soon to predict the future of the newly discovered Fairbanks placers, but they show every evidence of handsome profits. The facts presented by Mr. Prindle indicate that the conditions of occurrence of the gold are such that for profitable exploitation it must be mined by improved methods, and should invite the attention of capitalists. The fact that the placers are within a few miles of water transportation on the Tanana will permit the introduction of machinery at much less cost than at some of the older camps.

The value of this publication is much increased because it becomes the medium of making public two reconnaissance maps of the region based on surveys by Mr. T. G. Gerdine in 1903. One map, on a scale of 1:250,000, extends from Fairbanks to Circle, and the other, on a scale of 1:625,000, embraces the entire Yukon-Tanana district.

The maps and the text of this report must be regarded as preliminary, for at this writing both geologic and topographic surveys are in progress in the same field.

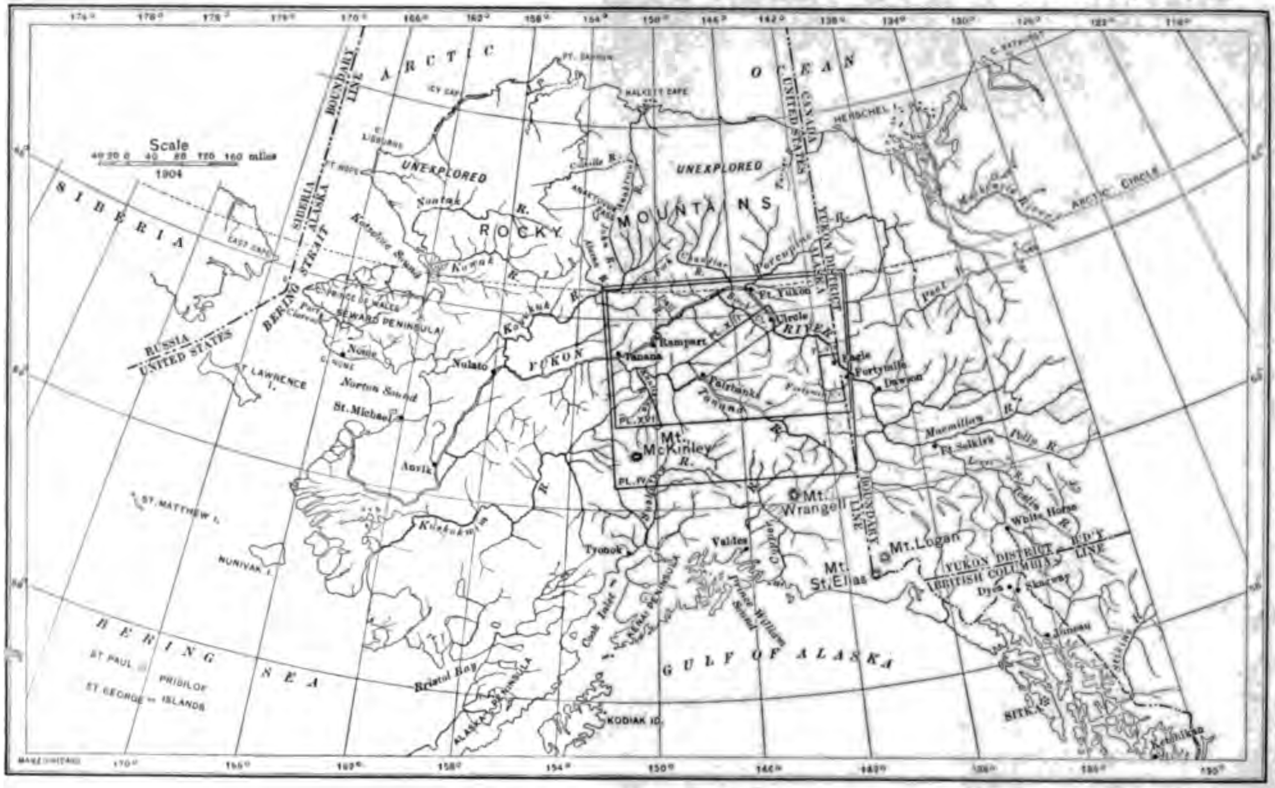
Very respectfully,

ALFRED H. BROOKS,

Geologist in Charge Division of Alaskan Mineral Resources.

Hon. CHARLES D. WALCOTT,

Director United States Geological Survey.



OUTLINE MAP OF ALASKA.

THE GOLD PLACERS OF FORTYMILE, BIRCH CREEK, AND FAIRBANKS REGIONS, ALASKA.

By L. M. Prindle.

INTRODUCTION.

GEOGRAPHIC RELATIONS.

The Yukon-Tanana interstream area, which includes from 35,000 to 40,000 square miles, is naturally delimited by the Yukon and Tanana rivers, which for some distance flow northwesterly in nearly parallel courses about 100 miles apart. At the Arctic Circle, however, the Yukon makes its great bend to the southwest, and, 200 miles farther on, near the one hundred and fifty-second meridian, in the central portion of Alaska, is joined by the Tanana (Pl. I). The area is thus irregularly shaped, its longer diameter extending northwest and southeast. On the east it is delimited by the international boundary—the one hundred and forty-first meridian—along which it extends to the south somewhat beyond the sixty-third parallel; on the north it just crosses the Arctic Circle (Pl. XVI, in pocket).

ECONOMIC DEVELOPMENT.

Some of the earliest prospecting in the interior was done in this area, and portions of it are comparatively well known. The discovery of placer gold on Fortymile in 1886, and the later discoveries in 1893 in the Birch Creek and Rampart regions, led to a rapid development of the creeks tributary to the Yukon. During the summer of 1902 placer gold was found in quantities of economic importance about 200 miles above the mouth of the Tanana and a few miles north of the river. This led to an influx of people and the formation of a center of population on the Tanana side of the area.

There are at the present time in the Yukon-Tanana country four widely separated regions which are producing placer gold—the Fortymile region, the Birch Creek region, the Rampart region, and the Fairbanks region. The Yukon and the Tanana are the main routes of travel, and from these rivers the gold-producing creeks are reached either by overland trails or by tributaries which are navigable for small boats.

Fortymile region (*Pl. VII*).—Eagle, the principal town of the Fortymile region, is pleasantly situated on the west side of the Yukon, about 100 miles below Dawson. There are trails to the placer camps in the vicinity of Fortymile Creek, 60 miles to the south, to the important localities on American Creek, only about 12 miles to the south, and to those scattered along the Seventymile, about 50 miles to the west. Eagle, so far as its location will allow, is a source of supply for this region; it has a population of about 300, and was incorporated in 1891. An army post is located there, and the town is the terminus of the Government trail and telegraph line from Valdes to the Yukon. There is also telegraphic communication with the upper Yukon, the whole region being thus brought into close touch with the rest of the world.

There are two main trails to the Fortymile country. One is by way of Thirteenmile Camp, Liberty Fork, and Dome Creek to the junction of Fortymile and Steele creeks, about 40 miles south from Eagle. The settlement at the mouth of Steele Creek is shown in Pl. II, *A*. Thence the trail follows the divide to the southwest, crosses South Fork at Franklin, and passes from the Fortymile region to the Kechumstuk Hills and the Tanana. This trail traverses most of the areas of economic importance, and all creeks where mining is in progress can be reached from it by side trails. It is generally followed by the mail carriers on the Valdes-Eagle route. Roadhouses are located at Steele Creek and on all the important gold-producing creeks. The other trail, known as the Government route, leaves the first at the Thirteenmile Camp, follows the long divide to the southwest between the headwaters of Champion and O'Brien creeks, and crosses North Fork at the telegraph office, about 8 miles above the "Kink."

In dry weather these trails afford good traveling for pack trains, but transportation of supplies is so expensive that most of the miners in the Fortymile area get their supplies elsewhere than at Eagle. In the absence of good roads the trade necessarily goes up the river, generally to Dawson; in this case duties must be paid at the boundary, and these add greatly to the burdens of the miner. Navigation on the Fortymile is rather difficult, as the current is frequently swift and rapids are numerous, but small boats carry freight as far as Chicken Creek on Mosquito Fork. Transportation rates to the Fortymile area by pack train during the summer are as high as 25 cents a pound, but in winter, when freighting is comparatively easy, the average is about 5 cents a pound. Most of the men buy their supplies at Dawson in the fall and have them freighted to the creeks during the winter. During the summer of 1903 prices of supplies on the creeks

A. STEELE CREEK, WITH FORTYMILE CREEK IN THE FOREGROUND.

B. GLACIER MOUNTAIN.

were found to be as high as 30 cents per pound for sugar, $8.50 for a 50-pound sack of flour, and 50 cents a pound for bacon.

The important localities on American Creek can be easily visited in a day's trip from Eagle by a trail which climbs the long spur west of American Creek, from which a comprehensive view of the whole area can be obtained, and then descends abruptly into the deep valley of the creek. In wet weather the trail is a rather hard one to travel. These localities can also be reached by following the Steele Creek trail about 10 miles to a point where a branch trail leads down a steep descent to Star Gulch.

The localities on the Seventymile where work is in progress are widely separated and are generally reached by a trail which crosses Mission Creek at its junction with Excelsior Creek, follows the ridge north of Excelsior, crosses Bryant about 4 miles from the mouth, climbs to the ridge on the west, and then drops down into the valley of the Seventymile and follows the stream to the falls; from the falls to Barney Creek it keeps on the north side, and in places is better along the base of the ridge; about half a mile above Barney Creek it leaves the river for the ridge on the north side. This is the starting point of the route overland from the Seventymile to the Birch Creek region, about 120 miles to the northwest from Eagle. The ridge to the south of the Seventymile is preferred by some of the miners in traveling from the upper Seventymile to Eagle. This is a high, dry trail that leads round the north end of Glacier Mountain, down the long spur between Excelsior and Mission creeks, and thence to Eagle.

Birch Creek region.—Circle, about 140 miles below Eagle, on the west side of the Yukon, is the local supply point for the diggings in the Birch Creek region, which are situated about 50 miles to the south, across the Yukon Flats, just within the edge of the plateau country. The trail between Circle and the gulches is direct and good during dry weather, but in long-continued rain it becomes difficult to travel. Twelvemile House, Central House, and Miller House are good road houses, situated at convenient intervals along the trail. Pack trains make regular trips from Circle to the gulches, the freight rates being about 25 cents a pound during the summer season; but, as in all the other regions, the heavy freighting is done in the winter.

Rampart region.—Rampart, which is about 170 miles below Circle, is the supply point for the men working in the neighboring gulches. There are trails up Little Minook Creek over the divide to the headwaters of Troublesome Creek and the Hutlina, and up the Minook to the Glenn Creek country, 25 miles south of Rampart.

Fairbanks region.—The new towns of Fairbanks and Chena are situated about 200 miles up the Tanana Valley. Chena is on the main river and Fairbanks is about 9 miles above, on a slough, while the gulches where work is being done are about 12 miles to the north. Fairbanks, which is about 200 miles due west of Eagle and 150 miles southwest of Circle, is accessible by trails from both places. That from Circle is the shorter and better. Stores are located at both places, and both are supply points for the camps. Only the smaller river boats, like the *Koyukuk* (a most useful type of boat, 120 feet long by 24 feet wide, with an average draft of 22 inches), are used on the Chena Slough. Chena, however, is accessible by the larger river boats. There are trails from both settlements to the creeks, but that from Chena is somewhat longer, and, following lower ground, is not so good a one to travel during the summer season. Where the trails pass through the timber they have been well cleared; along the creek bottoms they are often soft. Pack trains make regular trips and carry supplies at about the same rates as in the other regions. Various business interests are represented in the two towns, and three sawmills were in operation at Fairbanks in 1903, with a daily capacity of about 50,000 feet. The Government telegraph line along the Tanana has brought the region into close communication with the outside world.

The population of the two places, with that of the creeks, was about 800 in 1903, and over 4,000 in 1904.

CLIMATE AND VEGETATION.

Although the winters are intensely cold, the summers are much warmer than is generally supposed, and the great number of hours during which the sun is above the horizon compensates for the shortness of the summer; the weather is often hot; frosts are generally uncommon, and the conditions are favorable for the development of an abundant vegetation.

The most common trees are the spruce, aspen, and birch, while alder and willow grow thickly along the stream courses, and a scattering growth of tamarack is found in the valleys of the Yukon and Tanana rivers. Spruce grows abundantly in the valleys of the larger streams and attains considerable size; throughout the area it is found along the steep slopes of the deep gulches as high as the climatic conditions will permit, and even covers with a light growth the lower ridges in the vicinity of the main drainage lines. The higher slopes and ridges are often covered with dwarf birch and alder, which finally give place to the moss-covered surface of the divides. The aspen is found abundantly along the stream bottoms, and birch is common near the large rivers.

Feed for stock is found in the headwater valleys of the streams throughout most of the region and is generally abundant along the larger streams. At Eagle, and also near Central House, in the Birch

Creek region, hay is put up for use during the winter months, and in portions of the Tanana Valley grass grows luxuriantly. One of the interesting sights of the trip was that of a bunch of cattle near the Tanana resting lazily in the warm sunshine of a September day surrounded by an abundance of good grass.

WORK OF THE SURVEY.

PREVIOUS WORK.

The Fortymile, Birch Creek, and Rampart regions were visited in 1896 by a survey party consisting of Spurr, Goodrich, and Schrader, the trip resulting in detailed descriptions of the gold-producing areas, an account of the developments that had been made up to that time, and sketch maps of the areas traversed.[a]

In 1898 Mr. Alfred H. Brooks,[b] of the Survey, studied the geography and geology along the Tanana side of the area and noted the lithologic resemblances to the gold-bearing rocks of the Fortymile and Birch Creek regions, described by Spurr. The valley of the Tanana was mapped, and in the same year another party, led by Mr. E. C. Barnard, made a map of the Fortymile region on a scale of about 4 miles to the inch (Pl. VII).

The trip of the Peters and Brooks party [c] of the Survey, in 1899, gave an opportunity for comparing the geology of this area with that of the country south of the Tanana, and to note the economic developments that had been made in the Fortymile region since the visit of the Spurr party.

In 1902 Mr. Collier studied the geology along the Yukon with special reference to the occurrence of coal, and investigated the gold placer diggings on Glenn Creek in the Rampart region.[d] During the same season the Brooks party from the Mount McKinley region crossed the Tanana at Tortella and studied a section of the area from this river to Rampart.[e]

WORK OF 1903.

Exploitation has been steadily carried forward since Spurr's investigations, and the camps have continued to develop in spite of the great discoveries at Dawson and Nome. Miners who have tried their luck at these more promising localities have often returned to make a living at the old camps, where many of the pioneers are now to be found. In consequence of these developments and of the demands on the part of the public for information in regard to these districts, two Geological Survey parties were sent to this field in the season of 1903, one under charge of Mr. T. G. Gerdine, to make a topographic survey between Eagle and the Tanana and from Tanana to Circle; and the other, under charge of the writer, to study, so far as possible within the limits of a single field season, the occurrence of gold in the placers of the districts which have been mentioned, and to extend the studies of the geologic problems. The following report includes only the results of immediate economic bearing, the publication of the geology being deferred until further studies have been made.

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[a] Spurr, J. E., Geology of the Yukon gold districts, Alaska: Eighteenth Ann. Rept. U. S. Geol Survey, pt. 3, 1898, pp. 87–392.

[b] A reconnaissance in the Tanana and White river basins, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. 7, pp. 425–494.

[c] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska, including a description of the copper deposits on the Copper and Tanana rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 331–391.

[d] Collier, Arthur J., The Glenn Creek gold mining district, Alaska: Bull. U. S. Geol. Survey No. 213, 1903, pp. 49–56; The coal resources of the Yukon, Alaska: Bul. U. S. Geol. Survey No. 218, 1903.

[e] Brooks, Alfred H., An exploration in the Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. — (in preparation).

Topographic party.—The combined topographic and geologic parties, in charge of Mr. T. G. Gerdine, topographer, traveled by way of Dawson to Eagle, arriving there June 16. Mr. Gerdine, with Mr. R. B. Oliver (assistant), 6 men, and 14 horses, began the topographic work about 30 miles west of Eagle and carried a belt of reconnaissance mapping to the southwest into the Goodpaster Valley, and thence across the Salcha nearly to Fairbanks. Here, unfortunately, the surveys were interrupted by a dense pall of smoke from forest fires, but they were begun again at Fairbanks, on the Tanana, and carried northeast through the new gold district as well as through the older Birch Creek diggings, and thence to Circle, on the Yukon, which was reached about the middle of September. Within the limits of one season Messrs. Gerdine and Oliver completed the reconnaissance mapping of over 6,000 square miles, and much of the value of this report rests in the fact that through it these cartographic results are presented to the public. The map of the Fairbanks-Birch Creek regions, on a scale of about 4 miles to the inch (1:250000), includes the region between the Tanana and Circle (Pl. XIII). A second map (Pl. XVI) has been prepared, on a scale of 10 miles to the inch (1:625000), of the entire region, which embraces not only Mr. Gerdine's surveys, but all those that were previously made in the entire Yukon-Tanana region.

Geologic party.—The writer's party, which included a packer, a cook, and 7 horses, began work at Eagle on June 16 and continued it until the close of the season at Fairbanks on September 12, during which time about 400 miles were traveled. Eighty-eight days were available for work, fifty-five of which were bright and clear. The latter part of June and July were spent in the placer camps of the Fortymile area, those near Eagle, and those on the Seventymile; the month of August in traveling from Eagle to Birch Creek and in studying the placers of the Birch Creek region; and the time that remained in making a trip across country to the Tanana and in the Fairbanks placer region, where only four days were available for work.

The work was concentrated on the gold-producing creeks and localities where prospecting was in progress, with the aim of learning as much as possible in regard to the origin and distribution of the gold, the methods by which it is obtained, and the undeveloped possibilities of the older as well as the newer camps.

The journey naturally falls into four divisions—that from Eagle to the Fortymile country and return, that embraced by side trips in the vicinity of Eagle and to the Seventymile, that from Eagle to Birch Creek, and that from the Birch Creek region to the Tanana.

In the Fortymile region the writer visited Wade Creek, Walker Fork, Franklin Creek, Chicken Creek, North Fork of Fortymile, and several outlying localities where some work is being done; in the vicinity of Eagle, American Creek and Discovery Fork and the localities on the Seventymile; in the Birch Creek region, Deadwood, Mammoth, Mastodon, Miller, and Eagle creeks; in the Fairbanks region, Pedro, Cleary, and Fairbanks creeks.[a]

From Eagle (see map, Pl. VII) the party traveled south along the Steele Creek trail, crossed the Fortymile at Steele Creek and the South Fork at Franklin Creek, encircled the headwaters of Buckskin Creek to the telegraph line, and traveled thence to the "Kink," on North Fork of Fortymile, outside the area shown on the map. (Pl. VII.) From this point a good trail was followed along the divide in a northeasterly direction to Eagle. In crossing the country from Eagle to Birch Creek a northeasterly course was taken. The ridge to the north of the Seventymile at Flume Creek was found to offer good traveling, and farther to the west the northern slopes of a group of sharp peaks were traversed till a descent was made to Flat Creek. Charley Creek was crossed without difficulty at a point perhaps 30 miles above the mouth, where it flows in a meandering course in a narrow canyon. A divide was then followed for three days without crossing a single stream to the forks of South Fork of Birch Creek, keeping the northern tributary of this fork, with its deep canyons, on the north. Birch Creek was crossed at a point about 2 miles above where it emerges from the hills into the great flat country south from Circle, and the divide was followed round toward Deadwood Creek till a trail was found crossing the flat from the Hot Springs to Central House. The distance from Eagle to Central House in a straight line is about 120 miles. The course followed by the Survey party was found to be comparatively direct;

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[a] The writer, assisted by Mr. F. L. Hess, revisited the Fairbanks district in 1904, and it has been possible to embody in this report a description of the present developments in this portion of the Yukon-Tanana region.

the only points where difficulties may be encountered are at Charley River and Birch Creek, which at times of high water may become sources of delay, though at low water they present no difficulties. Charley River was easily crossed, but high water caused a delay of two days at Birch Creek.

From the Birch Creek region there is a direct and easy trail to the Tanana, by which Fairbanks, 150 miles to the southwest from Circle, was reached the night of September 11, just in time to take the steamer down the river next morning.

Conditions of travel.—Traveling through the Yukon-Tanana country with pack trains is comparatively easy. The trail keeps mostly to the divides, and these, except in rainy weather, generally afford good firm footing and can often be followed for two or three days without crossing the main drainage lines. The summer of 1903 was very dry in the Fortymile region, and the hot days of June and July, hazy with the smoke of many forest fires, hardened the trails and lowered the streams till the conditions were unusually favorable for travel.

When traveling on the high divides, which are covered only with moss or a sparse growth of dwarf birch and occasional clumps of alder, it is easy at camping time to drop down to the green valley of some small stream where the horses find the freshest grass and where the straggling spruces from the thickly covered slopes furnish abundant firewood. In these upper valleys caribou are frequently to be found in great abundance during the fall and winter months. Hundreds of them were encountered between the Seventymile and Birch Creek. They betrayed only curiosity at the presence of the pack train and were apparently migrating slowly toward the east.

The larger streams can generally be forded at low water, and at the points where the main trails cross them ferry boats are available for the transportation of passengers and outfits, while horses cross either by wading or swimming. At Fairbanks a wire-cable ferry has been constructed capable of carrying several horses with their packs.[a] A wire cable was also in use at Twelvemile, on Birch Creek. In case of sudden rain a stream like Birch Creek may rise several feet in a few hours, and the crossing, which was so easy while the water was low and clear, becomes an impossibility till the flood has subsided. Fortunately, with clear weather the water falls rapidly, and the crossing can be made in a day or so with little difficulty. This sudden change in character illustrates the delicate adjustment between the streams and the weather conditions, which results from the fact that, in consequence of the frozen character of most of the ground in the drainage areas, the rainfall finds its way rapidly to the streams.

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[a] A bridge has replaced the wire-cable ferry.

Road houses have been established at points along the main trails in the vicinity of the mining regions. Good board and bunks are to be had, and the cultivation of garden spots within the last few years has resulted in the addition of a wholesome variety of fresh vegetables to the ordinary Alaskan diet. Caribou, too, killed in the fall and winter months, are often kept in cold storage throughout the summer in ice houses or in old shafts, where at a depth of 20 to 30 feet the ground is always frozen. Grayling are abundant in the clear streams and are easily caught.

The members of the party during the journey often experienced the helpfulness and hospitality so characteristic of the prospector, and have occasion to look back with pleasure upon the days spent among men who have labored hard in a quiet way to satisfy the craving for individual independence and have gained through hardship something that is worth while even if their hopes are yet unrealized. In the hazy atmosphere of an after-dinner smoke in some neatly kept cabin bits of Alaskan exploration come to the surface which tell most forcibly the story of the days of 1898; or perhaps a blue column of smoke, faintly rising from the spruces of some lonely gulch, guides one to the temporary camp of a pioneer who has been in Alaska since the first discovery of gold. Over a cup of coffee, prepared in an old baking-powder can, one is made to understand the important part these men have played in the development of this portion of our possessions and their reasons for having learned to call it home.

GEOGRAPHIC DESCRIPTION.

TOPOGRAPHY.

The Yukon-Tanana area is only a portion of the great interior plateau which extends from the northern base of the Pacific Mountain system to the Rocky Mountains, far north of Yukon River and east and west throughout Alaska. The average altitude is about 3,000 feet above sea level, and the undulating surface presents a comparatively even sky line, broken by occasional, short, rugged, sharp-peaked ridges, which rise to a height of about 6,000 feet, and by lower, isolated prominences, locally known as "domes." (See map, Pl. XVI, in pocket.) The apparent continuity of the general surface is interrupted by many steep-walled valleys which have been incised to a depth of 1,000 to 3,000 feet and have made the area one of broad undulating divides and long flat-topped spurs, all of nearly uniform elevation. Toward the Yukon the plateau region breaks off abruptly to the river or to the surface of the large area known as the Yukon Flats, and the outer edge of it has frequently become a fringe of sharp ridges separating the many smaller streams in the vicinity of the river. On the southern side the ridges often persist to the Tanana, or become gradually lower toward its valley or those of its tributaries. The valleys, too, are more open than those on the Yukon side.

DRAINAGE.

There is no well-defined divide between the two rivers, and the drainage is carried away by their interlocking tributaries, which often pursue most irregular courses. The most important tributaries of the Yukon within this area are the Fortymile, Mission, Seventymile, Charley, Birch, Preacher, Beaver, Hess, and Minook; those of the Tanana are the Volkmar, Goodpaster, Salcha, Chena, Tolovana, and Baker.

FORTYMILE REGION.

General character.—The greater portion of the Fortymile region, about 2,100 square miles, is included in the Fortymile quadrangle, which was mapped by Mr. E. C. Barnard in 1898, and shown on Pl. VII of this report.

In this region the mountains are of two types—ridge and dome. Glacier Mountain, 15 miles west from Eagle, which is one of the most prominent examples of the ridge type, is partly shown in Pl. II, *B*. It is a gray, sharp-peaked ridge, with a northeast-southwest trend, an altitude of about 6,000 feet, and a length of about 10 miles. It forms a strong contrast to the surrounding country. From its flanks can be seen several domes which attain heights up to 5,000 or more feet. Fortymile Dome, about 15 miles south of the Yukon, along the boundary, is one of the most conspicuous examples. Between these types of prominences extends the undulating plateau-like areas interrupted by the valleys of many streams.

The Yukon River at Eagle is about 810 feet above sea level, and its tributaries have consequently a fall of something like 2,000 feet from their sources in the plateau country to the level of the main river. As the Yukon has been cutting for itself a narrow valley in the Yukon Plateau, so the many tributaries have been deepening their channels until the prevalent type is that of the canyon. The most important streams are the Fortymile, Mission, and Seventymile.

Fortymile system.—Fortymile Creek, which drains about two-thirds of the area, is formed by the union of North and South forks at a point about 45 miles southwest from Eagle and 25 miles west of the boundary and flows in a meandering easterly direction to the Yukon through a narrow valley (Pl. III, *A*), the bottom of which, where the forks join, is about 1,000 feet above sea level. From the higher elevations a few miles back long spurs descend toward the stream with gradual slopes, which at an elevation of about 500 feet above the stream and in places as far as a mile back from it are conspicuously benched. The bench can be traced all along this portion of the river and is the floor of an older valley formed by the stream and occupied by it at a period before the present canyon was commenced. This feature is well shown on the map of the Fortymile quadrangle (Pl. VII).

The Fortymile, which varies in width from 250 to 300 feet or more, carries a considerable volume of water, and often flows in long reaches of quiet water, separated by riffles caused by outcrops of bed rock across the stream. Navigation is rather difficult, but freight is carried in small boats as far as Chicken Creek on South Fork. At low water the stream is easily forded by pack animals.

North Fork, which drains a large area to the west and has numerous tributaries from the north toward Glacier Mountain, has sunk itself in a canyon like that of Fortymile, and flows in an easterly direction to the main river. South Fork, on the other hand, flows in a general northerly direction in a canyon which becomes more open toward the south and bends abruptly to the west about 15 miles above the forks; 5 miles beyond, it divides into Denison and Mosquito forks, which drain a large area to the south and west. Because of its placers, Chicken Creek is an important tributary of the latter. Walker Fork heads on the Canadian side, flows in an irregular westerly direction, and joins South Fork about 12 miles south of the main forks; it forms the southern boundary of an area containing several creeks of economic importance. Fortymile, between the forks and the boundary, receives from the south several small tributaries, of which Canyon Creek, about 5 miles west of the boundary, is the most important. A larger number of creeks are tributary from the north, but most of them are small. O'Brien Creek, however, gathers the drainage from an area extending 25 miles to the north, where its most distant sources are opposite those of American Creek.

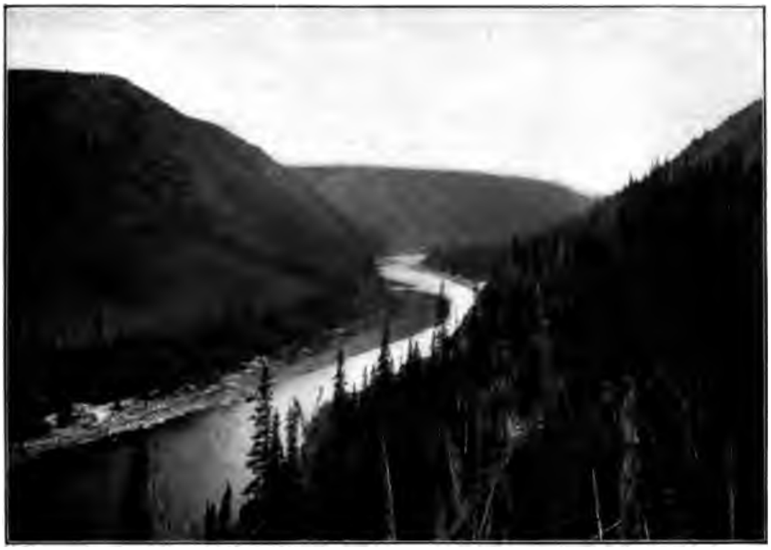
Mission Creek system.—The Mission Creek system drains the area between Glacier Mountain and Eagle. The headwaters of its many tributaries are cutting into the plateau surface far more vigorously than are those of the Fortymile system, which flow in less accentuated valleys on the southern side of the divide with the decreased power due to greater distance from the major stream. For the greater portion of their courses Mission Creek and its tributaries flow in a northeasterly direction. At the point where Excelsior Creek joins it the main stream turns nearly at right angles to its former direction, and flows southeast for a distance of about 8 miles to the Yukon. The valley through this part of its course is unsymmetrical, being bounded on the north by a steep ridge and on the south by a slope 3 or 4 miles in width, which rises gradually toward the higher level. The stream belongs to a smaller class than the Fortymile and is shallow and swift, with an average width of perhaps 30 feet. American Creek is its most important tributary.

Seventymile system.—The Seventymile, which is nearly the size of Fortymile, has a length of about 75 miles, and flows in a general easterly course, through a beautiful valley, to the Yukon, about 25 miles below Eagle. Its upper valley is of the canyon type, but at Barney Creek, about 30 miles west of Eagle, it becomes broader, and is bounded on the north by a high, steep ridge, and on the south by massive spurs that descend rather abruptly from the plateau region to the foot of a flat which is about one-half mile in width and from 10 to 20 feet above the level of the present stream. In the canyon portion the spurs from the hills to the south are even more clearly benched than are those on the Fortymile. The surface of the most prominent bench, 500 feet above the stream, is shown in the accompanying photograph (Pl. III, *B*). Farther south the hills rise to a height of about 2,500 feet or more above the river, and exhibit beautifully preserved rock-cut benches to their summits, which are flat topped, several acres in extent, and often correspond in level to the truncated tops of neighboring hills. The benches, except where obscured by gulches, can be traced around the hills; they are especially prominent on the spurs and occur at corresponding levels. The vertical distance between the step-like benches varies from a few feet to about 50 feet, the rise from one to the other often showing an outcrop of the bed rock. The rocks comprising this area are highly contorted metamorphic schists and granular intrusives. Whatever the bed rock or its attitude, the same forms have been developed and are most striking features of the landscape. Similar forms were observed in other localities on the northern side of the Yukon-Tanana country, but nowhere exhibited such development as in the valley of the Seventymile.

The tributaries from the north are short and enter the river through deep, narrow canyons. Some of those from the south attain a length of from 12 to 15 miles. Bryant, Mogul, Granite, and Flume are the most important. These head in beautiful open valleys, which become narrower as the main river is approached, until, in the lower portions, the streams flow through narrow canyons cut by them in the broad, flat bench, which, at the Seventymile, is about 500 feet above the stream.

The river can be easily forded on foot at low water, and with the exception of a short portage at the falls, is generally navigable for small boats nearly to Barney Creek.

The same type of country prevails from the Seventymile to the Birch Creek region. Ridges like Glacier Mountain, however, are more prominently developed. One extending from the Seventymile about opposite the mouth of Flume Creek for about 15 miles in a *westerly direction* is the most conspicuous example. The altitude is



A. CANYON OF FORTYMILE, 500 FEET BELOW THE LEVEL OF THE OLD VALLEY.

B. SURFACE OF BENCH, 500 FEET ABOVE LEVEL OF SEVENTYMILE.

about 6,000 feet, the same as that of Glacier Mountain; it has several sharp, precipitous peaks, and the northern slopes are deeply furrowed by minor streams. The country to the north is one of open valleys and broad interstream areas, where the minor lines of drainage have been gathered into a few main streams which flow in a northerly direction toward the Yukon.

The most important streams between the Seventymile and Birch Creek are Flat Creek and Charley River. The former, which is about 14 miles west from the mouth of Flume Creek, on the Seventymile, flows in a canyon within an older valley like that of the Seventymile, but is a much smaller stream. Charley River, which is 8 miles farther west, is of the Birch Creek type. It meanders in a narrow canyon about 500 feet deep, the course of which is northeasterly toward the Yukon. The river, which rises far in the interior, has a width in this lower portion of its course of 200 to 300 feet, can be easily forded on foot at low water, and is said to be navigable for small boats for a distance of 100 miles above its mouth.

BIRCH CREEK REGION.

General character.—This region, situated about 50 miles south of the Yukon at Circle, is shown on the reconnaissance map of the Birch Creek and Fairbanks districts (Pl. XIII). The general characteristics of prominent ridges, less prominent isolated domes, and an undulating plateau surface deeply incised by many streams are the same as in the Fortymile region. Here, however, the ridges descend to the surface of an extensive flat about 800 feet above sea level and 40 miles in width, which extends from their base to the Yukon. This ill-drained area is flecked with lakes and crossed by the meandering drainage from the plateau. A prominent ridge, similar to that of Glacier Mountain, can be seen from the plateau level about 40 miles to the west. The most prominent domes are Mastodon and Porcupine, 4,400 feet and about 4,900 feet, respectively, situated about 8 miles apart, near the area of economic interest.

Birch Creek system.—The creeks of importance all belong to the drainage system of Birch Creek, a stream comparable with Fortymile Creek, which receives many active tributaries ramifying far within the plateau, and, after flowing parallel with the Yukon in a long meandering northwesterly course, finally joins that stream below the great bend at the Arctic Circle (map, Pl. XVI). It is formed by North and South forks (which have southeast and northwest courses, respectively, to the point of union, just within the edge of the plateau) and flows northward through a narrow canyon into the Yukon flat. North Fork, which is the more powerful stream, drains a large area to the west and south, the headwaters interlocking with those of streams tributary to the Tanana. South Fork, 6 miles to the southeast of the main forks, divides into two strong tributaries, and these rapidly split up into numerous smaller streams which are deeply sunk within the region and interlock with the system of the Charley River to the east and southeast. The valleys of the two main forks are bounded to the north by a steep slope rising 1,000 feet or more above them. A well-defined bench about 100 feet above the present streams bounds the narrow valleys to the south, and extends, with a gradually rising slope, to the foot of the spurs which lead to the higher ridges. About 5 miles north of the hills Birch Creek is joined by Crooked Creek, which flows in an easterly direction through a broad, flat valley and receives the waters of several short, northward-flowing streams of economic importance, which drain the edge of the plateau. The wide flat of Crooked Creek merges into that of Birch.

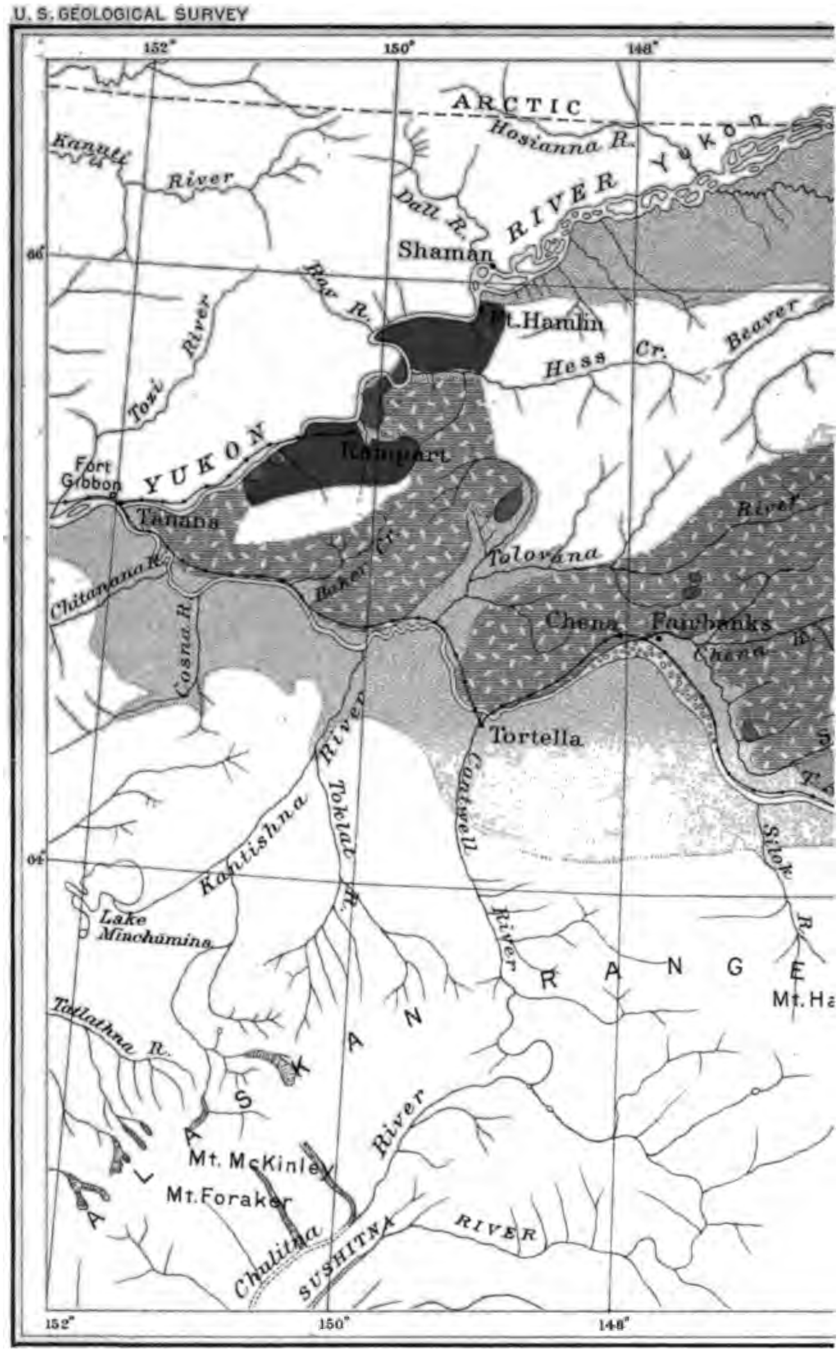
The valleys of Mission Creek, Seventymile, and of the forks of Birch Creek are similar in that they have an unsymmetrical section—steep slopes on the north and an open, more or less benched country to the south.

FAIRBANKS REGION.

General character.—This region occupies a position on the south border of the plateau country corresponding to that of the Birch Creek region on the north, and is also shown on the reconnaissance map of the two districts (Pl. XIII). The area in which there is present interest lies between Little Chena and Chatanika rivers, and is drained by their tributaries. The general character of the region is the same as that of Birch Creek, except that the plateau region descends more gradually to the valley of the Tanana and has somewhat lower average altitude. Domes which have received local names rise above the general level to a height of 2,600 to 3,000 feet above sea level. The valleys are more open than those to the north and the divides separating them are lower.

Chatanika and Chena rivers.—The Chatanika has its source far back in the plateau, and flows in a southwesterly direction to the Tanana. Twenty miles to the east is the Little Chena, which flows in a course parallel to the Chatanika and joins the Chena in the flats a few miles south of the plateau. The divide separating the Chatanika and the Little Chena extends in a southwesterly direction parallel to their courses and has been much dissected by minor tributaries, which flow to the northwest and the southeast, respectively, toward these streams. The occurrence of gold on these small streams has made the area one of economic importance. The distance

U. S. GEOLOGICAL SURVEY



GEOLOGIC RECONNAISSANCE MAP

By Louis M. Prindle, Arthur J. C

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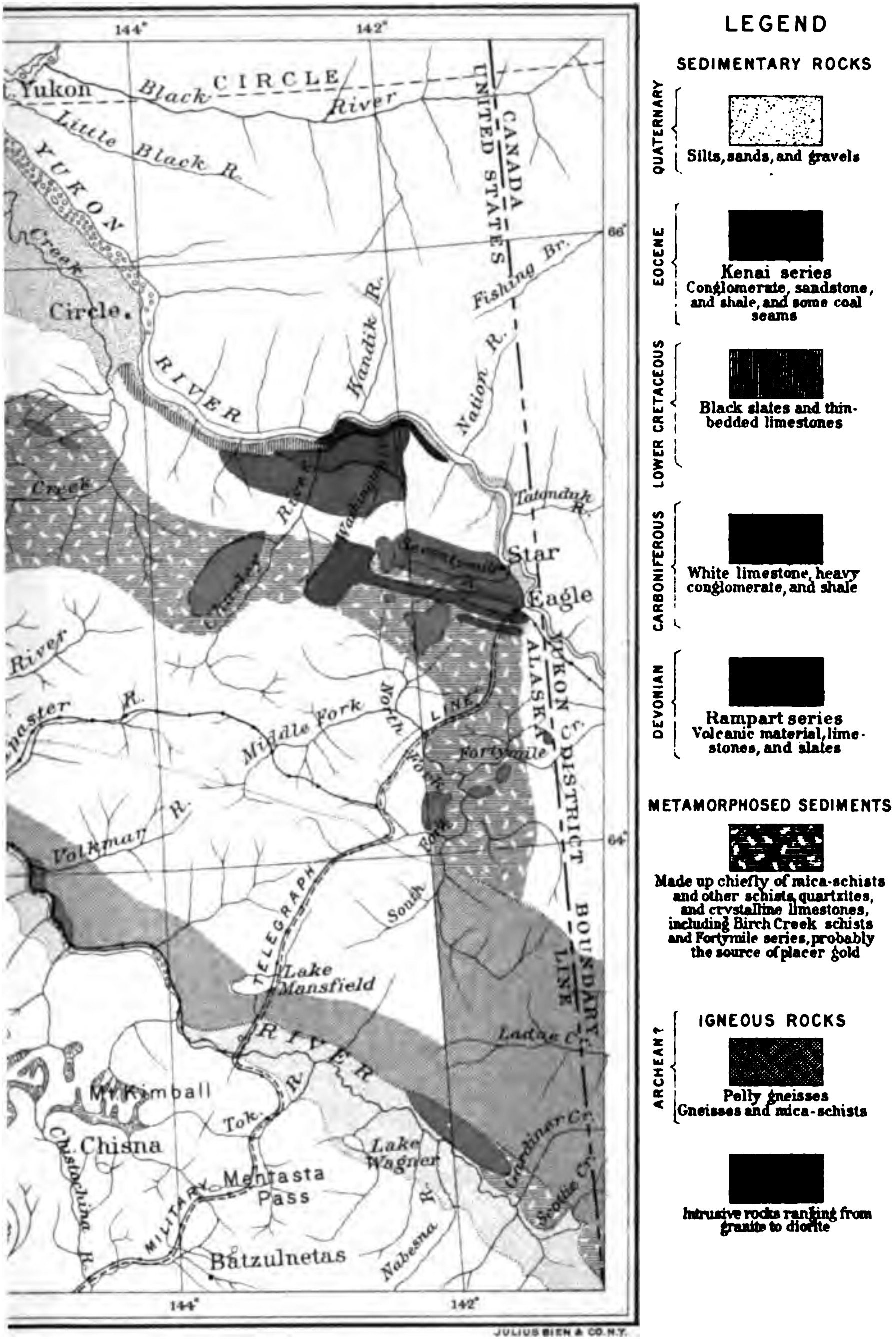

JULIUS BIEN & CO. N.Y.

UKON-TANANA REGION
H. Brooks

0 120 miles

from the plateau country across the flats to Tanana River is about 8 miles. The Chena Slough, however, from the main river, meanders along the northern limit of the flat and receives the streams soon after they leave the hills. The altitude of the slough at Fairbanks is approximately 450 feet.

GEOLOGIC SKETCH.

INTRODUCTION.

The shape and surface of the area have been briefly described, and the material or bed rock of which this block of country is composed next demands consideration. The attainment of detailed knowledge of a region of complex geology like that under discussion is the work of many years, but the results from the various reconnaissance surveys have thrown much light on the broader geologic problems, and these are epitomized in the table of stratigraphic succession to follow, as well as on the map (Pl. IV).

Both in the field and in the laboratory the writer's chief energies have been directed toward a study of the economic problems, to which the purely geologic investigations have been made entirely subordinate. In view of this and because more detailed studies of the stratigraphy are to be undertaken, only a few general conclusions in regard to the geology will be here presented. The stratigraphic succession of the general province will be presented in tabular form, but in the text only those formations and rocks which the writer has personally studied will be considered, and these chiefly from the standpoint of economic importance, the constant aim being to present such matter as will enable the miner to understand better the relation of the deposits in which he is interested to the bed rock in which they occur, or from which they have been derived.

The rocks include representatives of the igneous and sedimentary classes—those clearly formed by solidification from a molten condition and those which have been deposited through the agency of water—and the metamorphic rocks—a class most important in this region—which result from the alteration of either of the others.

Granite, which occurs abundantly in this area, illustrates the first class. The minerals of which it is composed have developed in place as the final result of the slow cooling to which the rock material has been subjected. With rapid cooling there would have been little opportunity for the development of minerals, and the molten mass would have consolidated as a product somewhat resembling the slag from a glass furnace. Coarse-grained, fine-grained, and glassy rocks, entirely different in appearance, may thus result from the same material simply through a difference in the conditions of solidification;

but whatever the conditions the resultant products have the earmarks of igneous origin.

Shale, sandstone, and conglomerate, which are very common in the Seventymile Valley, are composed, on the other hand, of mud, rounded grains, and pebbles, respectively, arranged in rather well-defined layers that give the coarser varieties a banded appearance. All lines of evidence lead to the conclusion that such characters are due to the reworking and sorting of material derived from older rocks and its subsequent deposition by water. Except that they are consolidated and folded, these rocks differ in no essential respect from similar deposits now in process of formation. Limestones also are known to have been deposited under water and often contain recognizable remains of organisms. The unaltered igneous and sedimentary rocks thus show their mode of origin by their characteristics.

The most widely distributed rocks within this area are the schists and gneisses, rocks which have been so changed by complex processes of metamorphism that their origin is often in doubt. The sedimentary and igneous rocks, in passing through the metamorphic mill, have had new minerals developed and new structures imposed upon them until their primary characteristics are obscured or replaced by those of a secondary nature. Further, these two classes, which are in places most intimately mingled, react on each other, and, beside the mutual results of such close relation, have often undergone together the processes of metamorphism. The formation of quartz veins is generally an accompaniment of these changes, while, locally, the quartz veins or the rocks themselves have been mineralized and become sources of some of the gold deposits, the discovery of which has made the region of importance and rendered the distribution of the metamorphic rocks a problem of economic interest.

STRATIGRAPHIC SUCCESSION.

An important purpose of all geologic work in any given province is to determine the sequence of the strata which outcrop in the area. In a region where the rocks have been much deformed the succession can be definitely established only after the most painstaking and detailed studies, which in the Yukon-Tanana region have not yet been begun. The results of the various surveys have, however, determined the succession of the larger subdivisions of a geologic time scale, which is presented in the following table. This scale, which is practically identical with that prepared by Mr. Collier[a] with the cooperation of Mr. Brooks, will, in connection with the map (Pl. IV), elucidate the general geologic features.

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[a] Collier, Arthur J., The coal resources of the Yukon: Bull. U. S. Geol. Survey No. 218, 1903, p. 15.

Provisional tabular statement of Yukon stratigraphy.

Age.	Formation name.	Contact relations.	Lithologic character.
Quaternary	Alluvium		Flood-plain deposits.
	Yukon silts	Unconformity	Fresh-water silts, sands, and gravels.
Post-Eocene:			
Tertiary		(?)	Sands, clays, and gravels.
Eocene	Kenai formation.	(?)	Fresh-water sandstones, shales, and conglomerates.
Upper Cretaceous.		Conformity?	Fresh-water and marine sandstones, shales, arkoses, and conglomerates.
Lower Cretaceous.		(?)	Fresh-water calcareous sandstones.
Do		Conformity	Marine, black, slaty shales, and thin-bedded limestones.
Permian		Unconformity	Marine, massive, white limestones, heavy conglomerates, and gray shales.
Mississippian		do	Marine, black slates, and thin-bedded limestones.
Devonian	Rampart formation.	(?)	Volcanic material, interbedded with limestone, slate, etc.
Pre-Devonian	Fortymile formation.	Unconformity	Schists and crystalline limestones.
Do	Birch Creek schists.	Conformity	Quartzites and schists.
Archean?	Pelly gneiss	Unconformity	Gneissoid and schistose granites.

The region visited by the writer is largely occupied by the metamorphic sediments called in the table the Birch Creek schists and the Fortymile formation, by the Devonian rocks (Rampart formation), by igneous intrusions, by Tertiary sandstones and conglomerates (Kenai), and by the Quaternary deposits. These formations will therefore be described, but the Carboniferous and Mesozoic horizons, which have not been studied by the writer, will receive no further consideration.

GEOLOGIC MAP.

Though much of the Yukon-Tanana country has not been surveyed in detail, yet the general facts of rock distribution indicated on the accompanying map (Pl. IV) are probably correct. The writer is only responsible for the geology of the central part of the area, that along the Yukon being based on Collier's work, while the southeastern and southwestern parts are based on the Brooks surveys.

It is of interest to note the general facts of distribution. A broad belt of gneisses and schists, termed the Pelly gneisses, stretches northwestward from the Canadian boundary probably to the Salcha Valley. These gneisses, provisionally assigned to the Archean, are flanked both north and south by the metamorphic sediments, which include the Birch Creek schists and Fortymile formation. These later occupy a broad zone, which is probably continuous from the Fortymile basin to the valley of Beaver Creek, interrupted only by smaller areas occupied by intrusives, or Devonian or Tertiary formations. The Devonian (Rampart formation) finds an irregular distribution in small patches in the eastern portion of the country; west of the Beaver Valley it attains an extensive development. Some Mississippian, Permian, and Cretaceous rocks outcrop along the Yukon between Eagle and Circle, and Carboniferous rocks have been found west of the Beaver Valley, but rocks of these ages have not been recognized elsewhere in the district, though it is quite possible that detailed surveys may discover them.

If this map has any significance to the placer miner, it lies in the distribution of the metamorphic sediments which nearly everywhere seem to be the source of the placer gold. It is possible that the igneous rocks of the Rampart formation may also be gold bearing, but in the placer districts studied by the writer the source of the gold seemed in most instances to lie in the metamorphic sediments. This fact leads to the conclusion that the most promising fields for prospecting will be the areas occupied by these metamorphic rocks. Furthermore, the prospector should pay special attention to localities in which igneous intrusives are plentiful, for the auriferous veins seem to be largely, if not entirely, confined to such associations. The economic importance of the Tertiary lies in its being the coal-bearing horizon of the district.

SEDIMENTARY AND METAMORPHIC FORMATIONS.

There are many unsolved problems regarding the subdivisions and stratigraphic succession of the rocks occurring in different regions of the Yukon-Tanana country. Gneisses, quartzite-schists, and schists of various kinds with interbedded crystalline limestones, have been considered as the oldest rocks and their relations have been studied by a number of observers. Gneisses and schists, possibly forming a basal complex, are most extensively developed in the southeastern portion of the country toward the Tanana, the quartzite-schists in the Birch Creek and Fairbanks regions, and schists with interbedded limestones in the valley of the Fortymile. In both the Birch Creek and Fortymile regions, however, the latter types occur in close relation, associated with local areas of gneiss. The problem of separation is further complicated by the close folding which the schists have undergone. These old rocks will be considered here in the order in which they have been mentioned, without laying too much stress on their separation, sequence, or age.

A formation composed of limestone, quartzite, shale, and chert beds, with closely associated tuffs, serpentine, and diabase, occurs above the older rocks, is much less metamorphosed, and is generally characterized by its green igneous content. This is the Rampart formation of Spurr.

The massive conglomerate and shales of the Kenai form the youngest consolidated sediments observed.

The Quaternary unconsolidated deposits include the bench gravels and stream deposits.

The igneous rocks are both intrusive and extrusive. There are granular representatives which vary in composition from acidic granite to gabbro, and occur, so far as known, as intrusive masses in all the formations but the Kenai. Extrusives are associated with the rocks of the Rampart formation, and some limited areas of fresh olivine-basalt that were encountered probably represent flows of comparatively recent origin. Dikes and sills are numerous and vary greatly in composition.

PELLY GNEISS.

Large areas of gneissoid rocks, provisionally assigned to the Archean, have been described, the most extensive one in the Yukon-Tanana country being found along the north side of the Tanana west from the boundary. This, as described by Brooks,[a] consists of rocks which vary in character from comparatively massive granite to mica-schists, and may include some sediments. The rocks generally exhibit a gneissoid structure due to dynamic metamorphism. Areas of similar rock in the vicinity of the Fortymile were studied by Spurr[b] and referred by him to the basal granite. Local areas of gneiss were observed in 1903, but the relations were not worked out in sufficient detail to justify definite conclusions as to their origin. It is believed, however, that they represent metamorphosed granitic intrusives, like those described by McConnell.[c]

BIRCH CREEK SCHISTS.

The quartzite-schists have been described and named by Spurr[d] the Birch Creek formation. These rocks are most extensively developed in the Birch Creek region and southward to the Tanana. The rock varies from a massive quartzite to quartz-mica-schist; a quartzite-schist is most common. At the one extreme is a pure, light-colored, massive quartzite, composed almost entirely of fine, rounded or interlocking quartz grains, with occasional grains of bluish quartz which attain a diameter of a millimeter or more. In other localities the rock breaks more easily along planes which show glistening flakes of mica on their surfaces. The quartz grains are still round, and the development of mica is practically the only change which has taken place; then the grains become elongated, the proportion of mica, both muscovite and biotite, increases, and finally, in some localities, the rock has become a quartz-mica-schist. Graphitic phases are common, and metamorphic minerals, especially garnet, are frequently developed during this process.

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[a] Brooks, Alfred H., A reconnaissance in the White and Tanana river basins, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 460–470; A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 356-358.

[b] Spurr, J. E., Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 134-137.

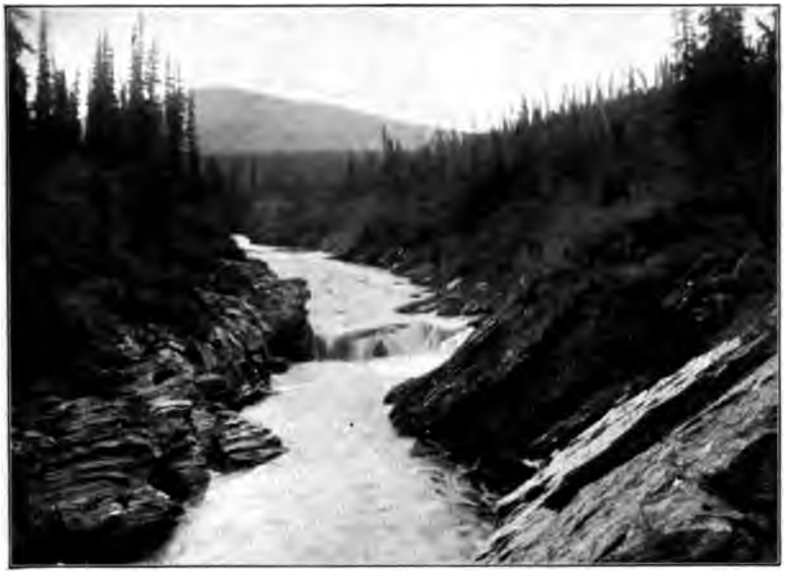
[c] McConnell, R. G., Note on the so-called basal granite of the Yukon Valley: Am. Geologist, vol. 30, 1902, pp. 55-62.

[d] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1896, pp. 140-145.

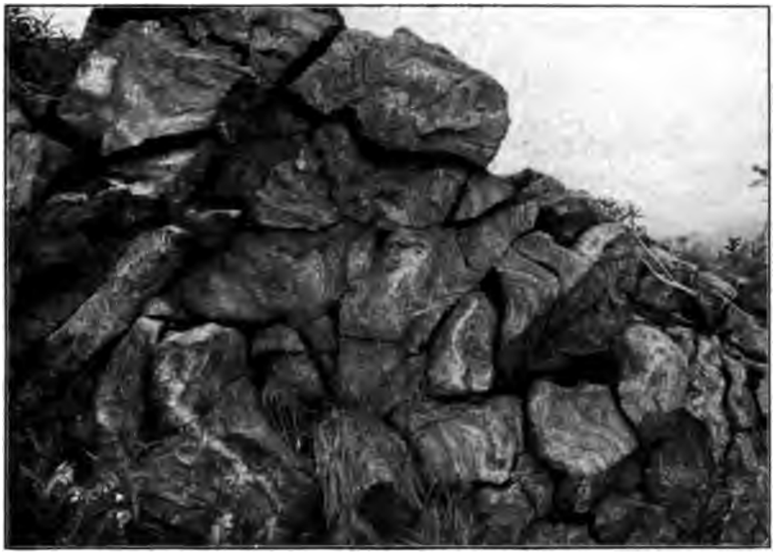
The rocks have not only undergone changes in composition, but have been folded upon themselves so closely that the structure is apparently simple. Examination, however, discloses minor folds with limbs so slightly divergent as to appear like separate beds of strata in nearly parallel positions; furthermore, the folds are often horizontal, and the area resembles one of slightly folded rocks. Most instructive examples of these closely appressed folds were observed along the trail from Circle to Fairbanks, the structure being apparently a characteristic one. Determinations of the thickness of these rocks become, therefore, very uncertain. The strike of the axial planes of the folds, where observable, is about east and west, and their dips have a maximum of about 45°; the most important system of joints strikes northwest.

In the section from the Birch Creek to the Fairbanks region, a distance of nearly 150 miles, the rocks show a great uniformity in composition. A small outcrop of closely folded calcareous beds was observed at the mouth of Mastodon Creek, in the Birch Creek region, and a small quantity of limestone is interbedded with the quartzite-schist about 16 miles northeast of Fairbanks Creek. The strike at this locality is N. 80° E., and the dip of the structure 30° to the south. Occasional feldspathic schists, which are possibly altered igneous rocks, were observed interbedded with the others. Intrusives occur in the Birch Creek region and in the Fairbanks region, but none were observed in the intervening area. The rocks contain numerous small quartz seams, and locally have been more or less mineralized. Pyrite is often seen in the schists, and pieces of schist have been found containing gold-bearing quartz. The gold in the placers of the Birch Creek and Fairbanks regions has been derived from these rocks.

The contact of these rocks with the Fortymile formation was not observed, but from the dominant lines of structure it would seem that



A. SCHISTS ON SOUTH FORK OF BIRCH CREEK.



B. CONTORTED SCHIST ON RIDGE NORTH OF MOSQUITO FORK.

they underlie the latter. The Fortymile rocks occur 6 miles east of the forks of Birch Creek, where they have a northwesterly strike and a northeasterly dip. Farther west the strike swerves round toward the north, and this would carry them outside of and dipping away from the rocks of the Birch Creek formation. The same formation occurs in the eastern portion of the Fortymile region, where their occurrence has been described by Spurr in the report to which reference has already been made.

FORTYMILE FORMATION.

The formation described and named by Spurr[a] the Fortymile series is most extensively developed in the Fortymile region. A fine exposure of the rocks composing this formation, however, is shown in the ridge referred to above between the forks of South Fork of Birch, about 6 miles east of the main forks of Birch Creek, where a long, irregular spur about 8 miles in length descends gradually toward the northwest between the deep, narrow valleys of the two forks. The roughest part of this spur is formed by outcrops of massive crystalline gray limestone, and the schists also contain occasional thin beds of limestone. In contrast to the quartzite-schists, these rocks vary greatly in character.

The most common rock is quartz-mica-schist, containing much garnet, staurolite, and biotite. Hornblende-schists occur, sometimes closely associated with limestone, and there are some thin beds of quartzite-schist. The strike, as already mentioned, is northwest, and the dip 20° to 45° to the northeast. The spur terminates abruptly in a prominent point 1,500 feet in altitude above the forks and 1½ miles to the east of them. Just below the forks the stream has cut a narrow canyon in garnet and quartzite schists, which may be transitional to the Birch Creek formation. The thin-bedded character of the schists, their northeasterly dip, and the spur of garnet-staurolite-schist to the southeast are shown in Pl. V, *A*. They are here cut by small granitic dikes. The continuation along the strike of the Birch Creek rocks would carry them across the valley of Crooked Creek toward the Crazy Mountains. In the other direction they extend to the southeast, and to the south of the northern tributary of South Fork of Birch form a prominent ridge, which attains a height of about 4,000 feet, and is furrowed on its southern slopes by the deep canyons of minor tributaries. The strike is uniformly to the northwest and the dip to the northeast.

The Fortymile schists attain a strong development in the Fortymile region and have been described in detail by Spurr. They include mica, garnet, hornblende, quartzite, and graphite schists.

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[a] Op. cit., pp. 145–155.

Crystalline limestone occurs in beds from a few inches to 50 feet or more in thickness. The rocks are closely folded and have a variable strike and dip, with a general structure nearly east and west. Contorted strata of hornblende-schist are shown in Pl. V, *B*. These rocks, like those of the Birch Creek region, contain many quartz veins. Locally the rocks and the veins have been mineralized and become the source of gold.

In the Fortymile region they have been intruded most complexly by igneous rocks. Some of these have undergone metamorphism along with the schists and have become an intimate part of them, while others are fresh and vary in size from large intrusive masses down to thin sheets and narrow dikes. The accompanying photograph (Pl. VI, *A*) shows a typical outcrop of hornblende-schist with a granitic sheet 6 inches in thickness parallel to the schistosity. In prospecting the rocks of the Fortymile formation the marble beds have often been taken for veins, and much labor has been lost. They are often in a nearly vertical position on account of the close folding which the rocks have undergone, but an examination will show that they form an integral portion of the country rock, and can be traced sometimes for an indefinite distance.

These schists are prominently developed on all of the gold-producing creeks of the Fortymile area, with the exception of Chicken Creek. They occur to the southwest of the Fortymile quadrangle around the head of the Buckskin, along Confederate Creek, and on North Fork of Fortymile Creek. They were observed also far to the west, along Charley River.

In the northern portion of the Fortymile quadrangle the areal boundaries are not clearly determinated. Hornblende-schists and schistose limestones occur at the falls on the Seventymile, and are provisionally correlated with the Fortymile rocks. Quartzite-schists, similar to schists of the Fortymile, dip away to the east and west from the northern termination of the intrusive mass of Glacier Mountain. It seems best at present to draw the boundary between the quartzite-schists, which are often graphitic, and the limestone, which at several localities occurs to the north of them and is included provisionally in the Rampart formation. This limits the northern extension of these rocks to a line running northwesterly from the headwaters of American Creek. The boundary between this and the succeeding formation is probably very irregular.

The Birch Creek and Fortymile formations and all the other metamorphic schists were included by Brooks[a] under the name of Kotlo series, and in the geologic map (Pl. IV) no attempt has been made to differentiate the various members. The age of these rocks

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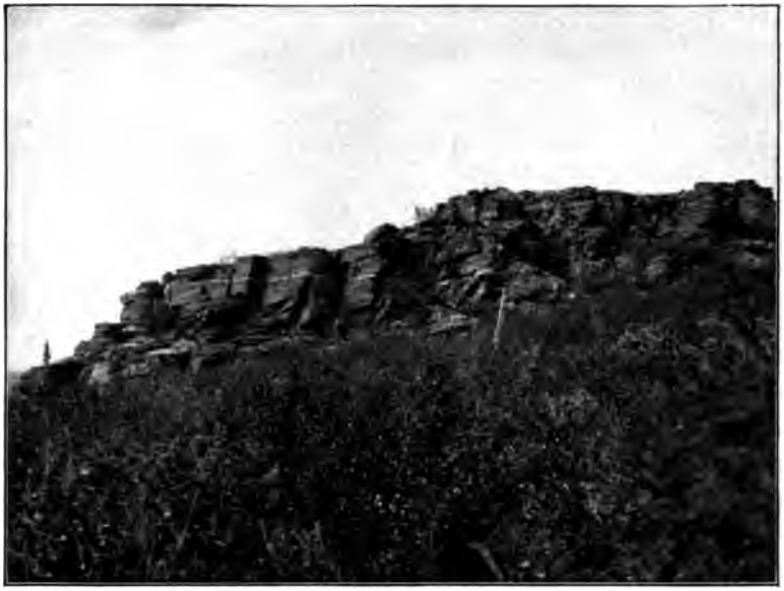
[a] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: *Twenty-first Ann. Rept. U. S. Geol. Survey*, pt. 2, 1900, pp. 357-358.



A. SCHISTS WITH THIN GRANITIC SILL ON TRAIL FROM WADE CREEK TO WALKER FORK.

B. VIEW UP WADE CREEK.

is undetermined, though they are known to be older than the Devonian and therefore will fall in the lower Paleozoic or pre-Cambrian.

RAMPART FORMATION.

This formation also was described by Spurr[a] in the report to which reference has already been made. It includes limestones, quartzites, black slaty shales, cherts, green shales with interbedded tuffs, and a mass of igneous material, mostly serpentine, diabase, and fine-grained fragmental volcanics, which have imparted a characteristic green color to the formation. A problem arises in drawing the boundary between these rocks and those of greater age. In discussing the Fortymile formation the line was drawn between a quartzite-schist and a rather massive limestone. Several sections were observed where, in passing from schists believed to belong to the Fortymile formation toward the rocks that are characteristically Rampart, a limestone occurs closely associated with the green igneous rocks. Such a limestone outcrops just below the forks of Bryant Creek, where it forms a steep slope about 200 feet in height, contains some fine-grained chert-like, siliceous beds, and is in close contact with the green igneous rock. The ridge to the north of Excelsior Creek and along the north side of Mission Creek has at its base a low sharp ridge of quartzite-schist with quartz veins, which may possibly belong to the Fortymile formation. This is separated by a timbered hollow from the main ridge, which is composed of gray limestone about 150 feet in thickness, capped by a very fine-grained, green, vesicular, diabasic rock. This limestone, which forms prominent outcrops all along the steep slope toward Eagle, has frequently associated with it black shaly slates and is everywhere capped by the igneous rock.

In the Fortymile region south of Eagle, between the graphitic quartz-schist and the green schists north of Thirteenmile camp, there is a limestone which occasionally yields fossils. Only crinoid stems were found, and these are of little stratigraphic value, but it is believed that this limestone, like those above mentioned, is more closely related to the green rocks than to those of the Fortymile formation. A dark shaly limestone and dark shales occur also between the greenstone area south of King Solomon Creek and the metamorphic schists to the north of this creek. It is deemed best, in view of the little evidence at present available, to include all the rocks above described in the Rampart formation. The members of this formation have been metamorphosed far less than those of the Fortymile. They are well developed on American Creek and on the ridge to the west, froming a belt several miles wide, with a northwest-southeast trend. This belt crosses Bryant Creek just below the forks and covers a considerable area to the south of the Seventymile; it also crosses Granite Creek and the lower part of Flume Creek, and farther west lies to the north of the Seventymile. The serpentines, with their diabasic dikes and a medium-grained massive gabbro, become prominent in the high ridge which extends from the Seventymile toward Charley River.

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[a] Op. cit., pp. 155-160.

Another narrower belt, which also seems to have a northwesterly trend, occurs to the south of King Solomon Creek. The rocks are found again to the southeast of the Fortymile quadrangle and in the far southwest between Chicken Creek and South Fork. The dark shales at this locality, which carry gold in calcite seams, are also referred provisionally to this formation. These rocks seem to overlie unconformably the Fortymile rocks. Their age is probably Devonian.

KENAI FORMATION.

Far younger than the rocks above described are those of the Kenai formation of Eocene age. They are best displayed in the lower valley of the Seventymile, where the river is bounded on either side by high ridges of massive conglomerate, with interbedded leaf-bearing shales. These occur on the lower part of Bryant Creek in an almost continuous section nearly a mile wide. The creek flows northeast. About 4 miles above the mouth occur thin-bedded gray and black shales, grits, and a small amount of conglomerate. In the shales are numerous heavy, yellow, ferruginous nodules, often containing plant remains, which are also abundant in the thin-bedded grits. The strike is about N. 70° E., and the dip 15° to the north. About 700 feet downstream are precipitous slopes of conglomerate with an east-west strike across the stream and a nearly vertical dip. Great slabs of this compact rock have fallen from the slopes and lie weathering at their bases. These beds, with possibly some shales, occur over a width of about 3,000 feet and are succeeded by 60 feet of dark and gray paper shales and grit, with the same strike and dip and in close contact with conglomerate on both sides. The shales contain many plant remains, and the sandy beds of the conglomerate next to them exhibit irregular impressions a foot or more long and up to 4 inches wide. These show generally well-defined linear markings, and there seems little doubt that they represent some form of vegetable life. The shales are succeeded by 350 feet of conglomerate, and this by more fine sediments 50 feet thick, composed of gray, micaceous, somewhat loosely consolidated, leaf-bearing shales and grits and fine-grained compact shales, where the leaves are beautifully preserved. These shale beds, like the others, are in contact on both sides with conglomerate; that on the downstream side outcrops with possibly some interbedded shales for nearly a quarter of a mile to a point where a wooded slope descends gradually toward the Seventymile. Precipitous slopes were seen nearly 2 miles to the north across Seventymile. These were not visited, but in the continuation of these slopes a few miles to the west the same formation was found. The maximum size of pebbles observed in the conglomerate was 5 inches; the average was from 1 to 3 inches. The material is mostly black, gray, and green chert, quartzite, and vein quartz. The rock grades into a sandstone containing black chert pebbles in a sandstone cement resembling mortar. All the way to Barney Creek the ridge on the north side of the river is made up of this formation, either nearly vertical or dipping steeply toward the valley. The cement contains much ferruginous matter, and the rock breaks down easily into its constituent materials, which form loose heaps of gravel and sand. The strong, abrupt spurs on the south of Seventymile are also of this material as far as the falls. The steepness of the dip is well shown in the nearly vertical position of the leaves so abundant in the shale.

On the west side of Mission Creek, about 2 miles above Excelsior Creek, there is a bluff 150 feet high of similar conglomerate, composed mostly of chert and vein quartz. Some pebbles of quartzite-schist were seen. Brownish sandstone is associated with it and ferruginous nodules, both containing the same species of plant life that were found on Bryant Creek. The dip is 50° to the northwest.

A similar conglomerate occurs on Wolf Creek, about 1½ miles above its mouth, forming a bluff 125 feet high on the west side of the creek. The occurrence is very similar to that on Mission Creek; the conglomerate varies to a brownish sandstone, and its pebbles are mostly black and red chert and vein quartz with occasional pieces of granite and diorite. Some of the rock weathers easily and some is compact, like that of Seventymile. About 4 miles above the mouth of Wolf Creek, in the valley of a small tributary from the west, occur conglomerate, brown sandy beds, and clay. There is some associated coal, loose pieces of which, a foot or more in diameter, were seen at the head of the creek; a few shallow prospect holes had been sunk to determine its amount. The coal contains grains of soft, brittle amber. Nodules similar to those on the Seventymile were found which contained ill-preserved plant remains correlatable probably with those of the Seventymile. The low ridge directly south of Eagle is also composed of conglomerate, which continues for 4 miles southwest from Eagle, on the trail to American Creek, up to an altitude of about 2,000 feet. This is probably an extension of that on Wolf and Mission creeks. As in other localities, the conglomerate breaks down easily into constituents, and the gravels thus formed may readily be mistaken for more recent deposits. Conglomerate occurs again about half way between the mouth of Excelsior Creek and Glacier Mountain. This may be an independent belt or an extension from the main mass.

In the Chicken Creek area patches of sandstone occur, with associated shale and coal and possibly some loosely consolidated conglomerate. As on Seventymile and Wolf creeks, there are ferruginous nodules which contain fragments of dicotyledonous leaves. The sandstone and shales also contain plant remains, badly preserved, but indicating the relationship of these beds with the Kenai, to which they are provisionally referred.

Until more detailed studies are made it has seemed best to correlate with the Eocene or Arctic Miocene the rocks of all the localities visited, where conglomerate beds occur associated with sandstone, shale, and coal. Plant remains are always present, and where determinable have been found to belong to this horizon. On Napoleon Creek there are conglomerates, sandstone, and coal-bearing beds similar to those on the Chicken, which, with those on the Chicken, have been referred by Spurr and Schrader[a] to the Mission Creek formation. The problem of the relations of the younger rocks to the underlying metamorphics and to each other requires detailed work for its solution.

A deposit on the west side of Mission Creek, about a quarter of a mile above the mouth of the Excelsior, unlike any seen elsewhere by the writer, was described by Schrader[b] in Spurr's report. The bluff, here 90 feet high, is composed mostly of very slightly consolidated, angular, granitic material. Fragments of coarsely porphyritic light-colored granite 2 feet in diameter occur. There is much fine material of the same nature and a few water-worn pebbles, but apparently no chert pebbles. Some thin-layered beds of gray sandstone and clay beds with carbonaceous matter occur. The outcrop has a thickness of about 30 feet and is tilted with a dip of 50° to the south; the strike is N. 35° W. It is capped unconformably with 20 feet of coarse stream gravels. The locality is about 1½ miles below the bluff on Mission Creek, where the Kenai conglomerate with characteristic fossils was found; the nearest outcrop on the north is quartzite-schist at the foot of the hill, a quarter of a mile distant. It is referred provisionally to the Kenai.

QUATERNARY DEPOSITS.

Bench gravels.—Bench gravels are common and attain their greatest development near the larger streams. They have been observed in many valleys of the Fortymile region and at various heights. The land

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[a] Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 175–176.

[b] Op. cit., p. 339.

has undergone many changes in level, which have been recorded on the valley sides by benches and deposits of gravel, which indicate the former water levels just as mud and driftwood register the level of high water in a stream. The simplest case is perhaps that of Seventymile Creek, where the stream is at present sunk, with nearly vertical banks, to a depth of about 20 feet within an older valley a half mile or more in width. The floor of the older valley, which is comparatively flat, is formed of the upturned beds of the conglomerate and shale. Before the stream commenced to cut its present shallow canyon it had deposited gravels widely over the surface of the valley floor, where they have been left. The tributaries necessarily had a similar development. The clean-cut rock bench near the mouth of Flume Creek, 20 feet in height, capped by several feet of gravel, is the best example that was observed. The conditions here at a level of only 20 feet above the present stream were repeated at various levels. The greatest height at which stream gravels occur on the Seventymile has not been determined. The most prominent bench is 500 feet above the water, but no gravels were observed at this level (Pl. III, *B*). On Mission Creek, about a mile below the mouth of Excelsior, there is a bench 15 feet high, capped by about 7 feet of gravel, and a short distance above the mouth of Excelsior, on Mission Creek, a bluff 70 feet high, capped by 20 feet of stream gravels.

The Fortymile and its tributaries are prominently benched. The most extensive of these benches, like that on the Seventymile, is 500 to 600 feet above the stream. Gravels were observed near Bonanza Bar 200 feet above the stream, and gold in paying quantities was reported in the high gravels nearly opposite Steele Creek. On Chicken Creek bench gravels are found 275 feet above the creek, and the discovery of good values in them is leading to an investigation of similar deposits in many places.

Stream gravels.—The gravels of the present streams have been derived, so far as has been observed, from the material within their immediate drainage areas, either that of the bed rock or of older gravels within their borders. Bars were worked extensively in the early days on the Fortymile, and at the present time a small amount of this kind of work is being done.

IGNEOUS ROCKS.

Igneous rocks occur in great variety in the Yukon-Tanana country. Those of the Fortymile and Birch Creek regions have been described in detail by Spurr,[a] and only a brief reference to the most important kinds and occurrences will here be undertaken.

The intrusives are granite, diorite, and gabbro, with many intermediate types and altered derivatives. The extrusives, so far as known, are diabases and basalts.[a]

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[a] Op. cit., pp. 225–250.

GRANITE.

The granites vary greatly in composition and may be roughly divided into three varieties—alaskite, biotite-granite, and hornblende-granite. The alaskite is composed almost entirely of quartz and feldspar; it occurs generally as small unaltered dikes and sills in the schists. The relation of this rock to quartz veins has been described in detail by Spurr in the chapter to which reference has already been made. The biotite-granite has a darker color, due to the presence of a considerable proportion of biotite, and occurs sometimes in large areas. The largest mass observed is west of Charley River, where it was traversed for about 10 miles. The rock forms a bare ridge which attains an altitude of about 4,000 feet. It is an evenly granular, medium-grained biotite-granite, with pegmatitic areas and a local development of a gneissoid structure. A similar rock occurs commonly in the Fortymile region, and a fine porphyritic phase of it occurs in the Birch Creek region, where it is found on the gold-producing creeks. Some of the gneisses have probably been formed by metamorphism from granitic rocks which were perhaps older than the schists, and others, similar in character, from later intrusions which have been metamorphosed along with the rocks in which they are contained. There are some areas of hornblende-granite.

DIORITE.

Diorite occurs in limited quantity, and many rocks intermediate in composition between it and granite are found. These rocks resemble hornblende-granite, but contain much plagioclase and are more closely related to quartz-diorite. A rather fine-grained porphyritic variety of a rock, which is closely related to quartz-diorite and may be called a granodiorite-porphyry, occurs on Chicken Creek and is composed of corroded quartz phenocrysts, abundant plagioclase, orthoclase, much hornblende and biotite, considerable titanite, and apatite.

A large mass of a medium-grained fresh rock, varying in composition from granodiorite to quartz-diorite, forms the sharp gray ridge of Glacier Mountain, 20 miles west from Eagle, and covers a considerable area to the westward. Some of this rock contains abundant quartz, plagioclase, biotite, and hornblende. Other varieties contain considerable orthoclase. There is a fine, sharp, isolated peak, about 6,000 feet in height, on the westernmost fork of Charley River, composed of this same beautiful rock. This locality is bounded on the north by the large area of biotite-granite already described and on the west by schists. Like the granites, this rock also has its gneissoid facies, and some dikes of it show clearly the characteristic effects of dynamic metamorphism.

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[a] *During 1904 many detached areas of extrusives were observed southwest of the Fortymile quadrangle.*

GABBRO.

The most typical occurrence of gabbro is in the ridge that begins a short distance above the mouth of Flume Creek, on the north side of Seventymile Creek. As far as observed, this ridge is composed of gabbro and serpentine cut by diabasic dikes. The rough ridges and precipitous peaks in which these rocks express themselves make this region one of wild beauty. The gabbro is a dark, greenish-gray, evenly granular rock, composed of irregular, equidimensional grains of plagioclase and monoclinic pyroxene, with an average diameter of from 2 to 3 millimeters. Coarser varieties occur, and sometimes there is a parallel arrangement of the minerals. The distribution of this rock has not been determined. There is much serpentine and many dikes of diabase in the same area.

DIABASE AND BASALT.

Isolated diabasic dikes are common throughout the Fortymile and Birch Creek regions, but the most important occurrences are in the Rampart formation, which is made more prominent by the presence of these rocks than by the less conspicuous sedimentaries. The rocks, which probably comprised originally a complex of basaltic flows, dikes, and tuffs, are now greatly altered and contain a large proportion of serpentine. A fresh olivine basalt occurs sparingly. It is best developed on Chicken Creek, where it probably occurs as a flow. A small dike was observed on Confederate Creek, and on North Fork of Fortymile, a short distance above the " Kink," two dikes occur.

SUMMARY.

The region is a complex one, composed mostly of metamorphic rocks. The oldest rocks are believed to be the granites and gneisses of the southeastern portion, the contacts of which with later rocks are obscured by dynamic metamorphism and by the presence of similar rocks of intrusive origin. These are succeeded by a closely folded metamorphic complex, locally separable into the Birch Creek and Fortymile formations. The Rampart (Devonian) rocks, which unconformably overlie the others, contain a large proportion of volcanic material, and, like them, have been closely folded. Foldings, intrusions, the formation of quartz veins, and mineralization have probably taken place at several periods. The material of the Kenai was deposited on these older rocks, afterwards folded with all that had gone before, and still later worn with them by erosion to an undulating, more or less level, surface. Recent elevations and depressions have been many and have left their traces on the terraced slopes of many valleys and in accumulations of deposits, like those of the Yukon silts, which have not been touched upon in this description. There was a time, too, when volcanic dust from some distant source to the southward was deposited in a thin layer over large areas of the Fortymile region, where it occurs just beneath the surface as a deposit similar in appearance to quicklime.

FOSSILS.

The following report was prepared by Doctor Knowlton on the material collected from the various localities visited by the party:

Fossil plants obtained by L. M. Prindle from various localities during the season of 1903.

[By F. H. Knowlton.]

3AP 224. Irene Gulch, Chicken Creek: Fragments of stems, indeterminable.

3AP 224½. McDowell claim, Chicken Creek: Equisetum sp.

3AP 237. Mouth of creek, 1 mile west of Chicken: Black carbonaceous shale with minute plant fragments, indeterminable.

3AP 251. Chicken Creek: Fragments of dicotyledons, possibly Corylus MacQuarrii, but uncertain.

3AP 330. Wolf Creek: Taxodium dubium? Heer; Populus sp.

3AP 336. Branch of Wolf Creek: Populus, cf. P. Richardsoni Heer; dicotyledonous fragments.

3AP 337. Branch of Wolf Creek: Only fragments of stems and bark.

3AP 348. Bryant Creek: Sequoia Langsdorfii (Brgt.) Heer; Taxodium dubium? Heer; Populus arctica? Heer; Populus Richardsoni? Heer; Corylus MacQuarrii (Forbes) Heer; Quercus platania Heer; Betula prisca? Ett.

3AP 349. Bryant Creek: Sequoia Langsdorfii (Brgt.) Heer; Corylus MacQuarrii (Forbes) Heer; Populus arctica Heer; Populus Richardsoni? Heer; Juglans nigella? Heer.

3AP 350. Bryant Creek: Sequoia Langsdorfii (Brgt.) Heer; Equisetum sp.; Populus latior Heer; Populus Hookeri Heer; Fagus Deucalionis Unger; Quercus furcinervis (Ross M.) Unger; Juglans sp.?

3AP 355. Mogul Creek: Sequoia brevifolia? Heer; Corylus MacQuarrii (Forbes) Heer; Populus sp.?

3AP 432. Mission Creek, 2 miles above junction with Excelsior: Corylus MacQuarrii (Forbes) Heer; Betula prisca Ett.; Fagus Deucalionis Unger.

Listing the species from all the localities, we have the following:

Full list of species collected.

Sequoia Langsdorfii.
Sequoia brevifolia.
Taxodium dubium.
Populus arctica.
Populus latior.
Populus Richardsoni.
Populus Hookeri.
Corylus MacQuarrii.
Quercus furcinervis.
Quercus platania.
Fagus Deucalionis.
Betula prisca.
Juglans nigella.

Taking well into account the fact that not all of the above species are determined with absolute certainty, it is nevertheless perfectly clear that all are of the same age, and I do not hesitate to say that this is Arctic Miocene.[a] Not a trace of the Cretaceous element appears.

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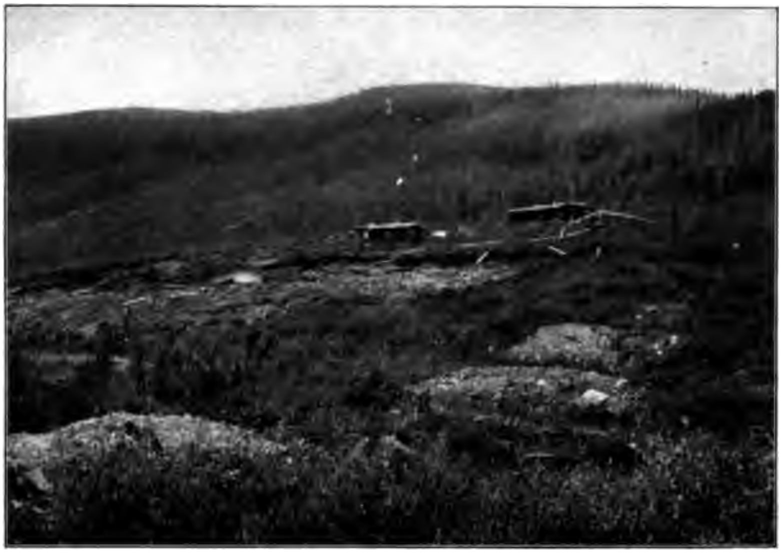
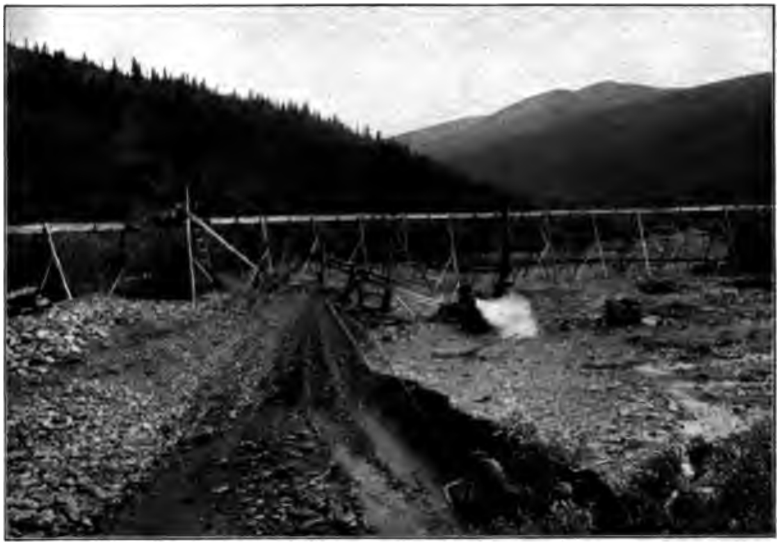
[a] This flora was first described as the Arctic Miocene. Subsequent investigations have shown that it is of Eocene age, but the old name is still retained.—L. M. Prindle.



A. WASHING THE OVERBURDEN FROM THE GOLD-BEARING GRAVELS, WADE CREEK.



B. STEAM SCRAPER WITH BUCKET CONVEYOR AT MOUTH OF POKER CREEK.

GOLD PLACERS.

FORTYMILE REGION.

FORTYMILE AREA.

Since the discovery of gold on Fortymile Creek, in 1886, prospectors have devoted much attention to its basin. The most important creeks at present are Wade, Walker Fork, Chicken, and Franklin, while some work is being done on the Fortymile itself, Napoleon Creek, the tributaries of Canyon Creek, and on North Fork of Fortymile. Prospecting is in progress in many places and still results occasionally in discoveries of economic importance.

Wade Creek.—The basin of Wade Creek, which is reached by trail from the mouth of Steele Creek, lies about 10 miles south of the Fortymile, and embraces about 50 square miles (map, Pl. VII). The creek, which is about 12 miles long, heads in Steele Dome, 3,750 feet high, and flows in a nearly straight southwesterly direction, entering Walker Fork a few miles above its mouth. There is a fall of about 600 feet from the upper limit of placer mining to the mouth—a distance of about 8 miles. The valley is sunk to a depth of about 1,500 feet within the plateau, and is narrow and V-shaped in its upper portion; lower down it gradually widens, finally merging into the valley of Walker Fork, where the stream follows a meandering course over the surface of a broad flat. The spurs from the northwest descend somewhat more gradually toward the stream than those from the opposite side, and the cross section of the valley is thus somewhat unsymmetrical. The general characteristics are shown in Pl. VI, *B*. The tributaries are short and flow in narrow V-shaped valleys. In dry seasons the demand for water far exceeds the supply, and much of the mining is brought to a standstill.

There is considerable timber on the northwest slopes of the valley, and a light growth of spruce on the southeast. The valley floor is generally covered with willows, but in the wider portion, toward Walker Fork, is well timbered with spruce and aspen. Dawson is the main source of supply, and most of the freighting is done during the winter.

The bed rock in which the valley of Wade Creek has been incised includes several varieties of schist and some ferruginous, thin-bedded limestone, which is apparently interbedded with the schist. Mica-schist and hornblende-schist are the most common rocks. Their attitude is variable, but the general strike is northeast, about parallel with the creek, and the dip of the schistosity varies from nearly horizontal to 50° or more to the southeast, while a prominent system of joints strikes N. 30° W. The schists are often contorted and the structure is probably complex. A small dike of basalt, with a strike of N. 60° E., was observed about a mile above Robinson Creek. Quartz veins are common in the schist and seem more abundant toward the head of the creek. Both bed rock and quartz veins contain in places considerable pyrite.

The gravels vary from 1 foot to 3 or more feet in thickness and are composed of the rocks that are found outcropping in the valley and along its slopes, no foreign material being observed. The proportion of vein quartz is small. The fragments are more or less angular, owing to the schistose and jointed structure of the bed rock, are little worn, and are generally less than a foot in diameter. They are found across the entire width of the valley and on the low bench-like termination of the spurs, perhaps 10 to 20 feet above the valley floor. The gravels are covered with a layer of muck up to 20 feet in thickness.

It is said that gold was discovered on this creek by Jack Wade about 1895. Rim prospects were found in the fall of 1898. The gold is rarely found more than 1½ feet above the bed rock in the gravels. Most of it is on bed rock and extends into it in crevices and along joint planes to a depth, in places, of 4 feet. It occurs rather irregularly, and the creek has the reputation of being spotted. Good pay was first struck on the rim at the terminations of the spurs on either side, and these became the favorite localities for work. The pay there is more accessible and found frequently in greater quantities than on the valley floor.

As much of the gold occurs as nuggets, which are irregularly distributed, it is difficult to form an idea of the average value of the ground. It is said to average about $100 to the box length of 12 by 12 feet, but some ground has yielded, by the winter's work, from 50 cents to $3 per cubic yard, including everything from surface to bed rock.

Much of the gold is picked up during the work, and many nuggets have been found. One was found during the winter of 1900 worth $216; and in January, 1903, one was picked up which measured 4½ by 1¾ by 1¼ inches and was worth $558. A week later another was found worth $437.85 in gold, valued at $17 to the ounce. The nuggets are well smoothed, of a bright yellow color, contain very little quartz, and are often convex on one side and more or less flat and irregular on the other. Some of the prospectors had observed that the nuggets found by them were generally rougher on the side lying next to bed rock. The larger nuggets have been found in the part of the valley which is about midway between the source and the mouth. The gold occurs generally as small flat pieces, and a large portion of that from the head of the creek is rusty. The little gold found in prospecting the side gulches differs in character from that in the main creek in that it is very rough and somewhat rusty. Very little fine gold is found, and the proportion of black sand is small. Barite is abundant, and its rounded pebbles are a characteristic associate of the gold. Black, shiny, rounded grains of hematite are also found.

The fact that no foreign wash was observed makes it probable that the gold has been derived directly from the drainage area of the creek itself. Many quartz seams and stringers occur in the schists, some of them of considerable thickness, but the quartz is not sufficient in quantity to make the proportion in the gravels a very large one. Pieces of gold with quartz attached are common. Both the schists and the quartz contain pyrite. One quartz vein occurring in the upper portion of the creek was found by assay for the Survey by E. E. Burlingame & Co., Denver, Colo., to carry 0.06 of an ounce of gold to the ton. It would seem from the information available that the gold has probably been derived from quartz veins and stringers in the schists and possibly also from mineralized areas in the schists themselves.

The mining developments are scattered along about 5 miles of the creek, commencing at a point about 4 miles above the mouth and extending toward the source. Claims are generally one-fourth of a mile lengthwise of the creek. There are two Discovery claims, and claims have been staked from each in both directions. The gold is mined by drifting, by hydraulic methods, and by open cuts.

Where the ground is deep and frozen some method of thawing is necessary. The most primitive way is by the wood fire. Hot water and hot rocks are sometimes used, either alone or in combination, but the most effective method is that of the steam thawer. The apparatus consists generally of a small boiler for the generation of steam, pipes for its transmission, and points. The latter are pipes, 4 feet or more in length, for driving into the frozen ground. They are connected near the one end with the steam pipe and provided at the pointed end with one or more small apertures, through which the steam rushes with greatly increased penetrative force, like water from the nozzle of an ordinary hose. They are placed against the frozen ground and driven in as fast as the ground becomes thawed. The quantity of steam can be easily regulated, and successful results on sinking and drifting depend largely on experience and good judgment in the use of the steam. Too much steam is liable to thaw the walls or roof of a drift to an undesirable extent and cause "sloughing," or falling in of the walls, with the consequent necessity of handling much more dirt than is necessary.

The drifting method is employed on Wade Creek mostly during the winter, the dump being washed out in the spring. On several of the claims the hydraulic method was in use in a small way. Pl. VIII, *A*, shows a claim being stripped of muck by this method. Ditches have been built up to about a mile in length, and when used in connection with canvas hose give sufficient head to strip the muck from the surface of the gravel, so that it can be reached and shoveled directly into the sluice boxes. The open-cut method is being introduced. For this the grade of the creek necessitates a bed-rock drain 700 feet or more in length. The muck, perhaps 7 feet thick, is stripped by ground sluicing and the gravel shoveled in.

As much of the best ground has been worked out, development is being carried laterally to the benches, which may furnish considerable gold. The difficulty, however, is to get sufficient water, the season of 1903 being a particularly bad one in this respect. The output for the year 1902–3 was generally supposed to be about $50,000, and the expense of working probably absorbed from 40 to 50 per cent of this amount. About 50 men were at work on the creek, and wages were $5 and board.

Walker Fork and neighboring localities.—The area of economic interest on Walker Fork is in the far southeast corner of the Fortymile quadrangle (Pl. VII) and extends from the boundary nearly to Cherry Creek, a distance of about 4 miles. It is reached from Wade Creek by a good trail of about 14 miles along the ridge, and also from points on the Canadian side, whence the supplies are generally obtained.

The headwaters of Walker Fork are small streams having their sources in the divide about a mile within Canadian territory. Poker and Davis creeks, which are the most important of these small streams, have narrow V-shaped valleys. Poker Creek flows directly west, about 1 mile of its short valley being on the American side. Davis Creek flows southwest in a similar valley and joins Walker Fork about one-fourth of a mile below Poker; it heads just beyond the boundary, about 1½ miles of its valley being on the American side. Both were described by Goodrich in Spurr's report.[a]

The course of Walker Fork below Davis is westerly, with a fall of about 100 feet to the mile. The valley is bounded on the north by a dome 3,380 feet high and to the south by a spur which descends gradually from an altitude of over 4,000 feet and terminates just south of the creek in a benched surface 400 feet high. The valley is about 2,000 feet above sea level and is unsymmetrical in cross section. Across the valley to the north the rise to the plateau level of about 3,000 feet is gradual and there is a bench corresponding to the one on the south. The slopes are covered with a light growth of small spruce, and the valley floor in places has produced timber of sufficient size for mining purposes.

The bed rock, similar to that of Wade Creek, includes quartzite-schists, graphitic schists, and garnet-hornblende-schists. Strikes were observed varying from 50° to 80° to the northeast, and the rocks have been closely folded. Quartz seams are common.

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[a] Spurr, J. E., Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. *Survey, pt. 3, pp. 326–331.*

The material on bed rock varies from 4 to 12 feet in thickness and includes muck, sand, gravel, and sometimes clay. In places there is no muck on the gravels, and rarely no gravels are found under the muck. The average thickness of the gravels is about 6 feet, generally exceeds 4 feet, and the maximum is 10 feet. A small amount of clay is sometimes found between the gravels and bed rock. Occasionally rounded quartz bowlders a foot or more in diameter are found, but the greatest proportion is composed of angular schist fragments of small size.

The thickness of the gravels increases gradually downstream, and from year to year it has been found profitable to work those of greater depth. Unlike Wade Creek, the gold is found not only on the bed rock, but in the gravels above bed rock through a distance oftentimes of 2 feet or more. In the bed rock it is found to a depth of 1½ feet. The pay streak has been worked in places over a width of 50 feet, but on the outer limits it contains small values. Ground has been worked, ranging in values to over $2 per cubic yard, and is said to run from $50 to $100 to the box length. The gold is found in pieces worth as high as $20, but the general run consists of small, flat pieces. Toward the head of the creek it is frequently black. Its origin is supposed to be in the small quartz stringers in the schist, which have sometimes been found to carry gold.

As the drainage area is small a dry season quickly affects the water supply, thus making the output of the creek, especially that of the upper portion, largely dependent on climatic conditions. The richest gravels on these creeks have apparently been worked out, but there is some ground left which could probably be made to pay if water were available. On Walker Fork several outfits have been doing fairly well during the past few years on ground that was not worked in the early days, and the present annual production is probably about $20,000 to $25,000.

Most mining has been carried on by the open-cut method. For this it has been found necessary, on account of the low grade of the stream, to construct bed-rock drains 400 to 1,000 feet in length. A horse scraper was in use on one claim to clear away the tailings, and on another a steam engine was in operation, running a scraper and a bucket conveyor to elevate the dirt to the sluice boxes, handling effectively 400 to 500 scrapers of dirt a day (Pl. VIII, *B*).

In July, 1903, about 40 men were working on Walker Fork and its tributaries, and wages were $4 a day with board.

The country south from Walker Fork on the headwaters of Cherry Creek is being prospected. The bed rock and gravels of this area are similar in character to those found on Walker Fork. At the junction of Owl and Crow creeks a little work had been done and some pay found, but the developments are not sufficient to give any indication as to the values of the ground.

Tributaries of Canyon Creek.—Some mining is being done north of Walker Fork over the divide on tributaries of Canyon Creek. Squaw Gulch is the most important tributary, and is easily reached by following the spur between Baby and Woods creeks. It heads in the divide opposite Wade Creek, and its tributaries have their source within a mile of those of the latter. In the lower 4 miles of its course it flows in a northeasterly direction and joins Canyon Creek about 6 miles above its mouth. It is a small stream with a fall of perhaps 150 feet to the mile. Its valley is narrow and V-shaped, and is sunk 1,500 feet below the level of the spurs on either side. The bed rock is marble, schist, and quartzite, which strike N. 45° W. and dip 30° to the northeast, and are cut occasionally by small granitic dikes.

The gravels are of the same types as the bed rock, and the proportion of bowlders is large, especially toward the mouth of the creek. The depth of gravel varies from 3 to 10 feet, the average being about 8 feet. Gold is found in about 1½ feet of gravel over widths up to 50 feet. It occurs as small flat pieces, often containing a considerable admixture of thin, flaky gold; but coarse pieces are common and specimens work $43 have been found. The best values thus far have averaged about $2 to the cubic yard, and the creek has produced a few thousand dollars. Considerable ditching has been done and dams have been built, but only a few men were on the creek in July. The flow, like that of other streams having small drainage areas, is closely dependent on climatic conditions and is immediately affected by drought.

Franklin Creek.—This creek and the conditions obtaining in 1897 were described by Goodrich in Spurr's report,[a] already referred to. Its mouth is at the end of the ridge trail from Steele Creek to South Fork of Fortymile, and is also on the Eagle-Valdes mail route. A small collection of cabins, picturesquely located on the small flat at the mouth, is known as Franklin and includes a post-office and road house.

Gold was discovered on this creek in 1886, and the early days are said to have been full of interest. One man's grub list in 1890 for two months consisted of 1 sack of flour and 5 pounds each of beans, rice, dried apples, and tea; the daily pancake was cut in three pieces, one for each meal. The gold was easy to mine and more easily spent on the little flat at the mouth of the creek, which was then crowded with miners, and passed quickly through many hands.

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[a] Spurr, J. E., Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. *Survey, pt. 3, 1898, pp. 332–335.*

The creek, which is a short one, about 8 miles in length, flows in an easterly direction and joins South Fork about 10 miles south of the junction. The valley of the upper portion is comparatively open, that of the lower portion is narrow and V-shaped, with precipitous slopes; the stream bottom has a width of only about 50 feet. The bed rock includes micaceous, garnetiferous, and hornblendic schists, and crystalline limestone, which strike nearly east and west and have a southerly dip; they show much crumpling locally, and have been closely folded. The schists were found to be cut in places by acidic granitic dikes.

The gravels are composed of more or less angular fragments of schist, crystalline limestone, granite, dark heavy rounded pieces of basalt, and heavy brown and green masses composed of garnet, epidote, and quartz often with considerable pyrite. The depth to bed rock varies from 2 to 30 feet, with an average of 8 to 10 feet. Pay is found mostly near bed rock and across the entire width of the creek bottom, and there is said to have been considerable ground which contained as high as $5 to the cubic yard. The ground worked recently has varied from about $30 to $150 to the square box length of 12 by 12 feet, which means a maximum value of about $3 per cubic yard. There has been much variation in the size of the gold. Two of the largest nuggets found in the creek were worth $239 and $500. The general run of gold at present rarely includes nuggets worth above $30.

The depth to bed rock on the bar at the mouth of the Franklin is about 3 feet; the gold there is found mostly on bed rock and to a depth of 2 feet within it. The average value is about $1 to the square foot of bed rock. There is no evidence that the gold on Franklin Creek has had other than a local origin. Pieces are often found with quartz attached, and an assay for the Survey, by E. E. Burlingame & Co., of a quartz fragment containing considerable pyrite yielded 0.16 of an ounce of gold and 0.16 of an ounce of silver to the ton. The average annual production at present is about $8,000.

Some winter drifting has been done on Franklin Creek, and in 1903–4 the bar at the mouth was worked with a steam-thawing apparatus, but most of the ground is better adapted for summer work, There are generally about twenty days of good water for sluicing and sixty days for shoveling in; this may continue to about September 20. The creek affords another illustration of the dependence of a small drainage area on abundant rain for satisfactory results. On July 4, 1903, there was only a small stream of water trickling through the gravel and standing here and there in disconnected pools; little work had been done since the middle of June. In one summer operations were entirely suspended from July 4 to August 15, while in 1902 conditions were favorable for work throughout the entire season.

Chicken Creek.—As one climbs the ridge south of Franklin a view is obtained far to the south with the peak of Fairplay in the background and the Kechumstuk Hills off to the west. (See map, Pl. VII.) In the foreground is the open valley of Chicken Creek, limited on the north by a rugged mass 3,400 feet in height, which occupies the right angle where South Fork bends to the west, and on the west by a broad flat spur between Chicken Creek and Mosquito Fork, which rises gradually to a level of about 2,000 feet, forming a striking feature in the landscape. In the middle distance Mosquito Fork crosses the region in an easterly direction and Denison Fork is seen coming in from the south. The valleys of all three streams are benched. The drainage area of Chicken Creek includes about 20 square miles of a fan-shaped area, which is only about 5 miles in length in a north-and-south direction. The tributaries converge from their sources in the divide between it and Franklin, thus giving an amphitheatral form to the upper valley. Below the last tributary the creek has a length of only about 1½ miles. It is a small one, flows in a southerly direction, and in the lower portion of its course has a fall of less than 80 feet to the mile. Of the tributaries, which flow in narrow valleys, the Stonehouse and Myers Fork are the most important. The valley of the main stream has a flat on the west which rises gradually until, at a distance of several hundred feet from the stream, it meets the foot of the broad, low spur west of Chicken Creek. This flat, as seen from the ridge between Chicken and Franklin creeks in July, 1900, was flecked with tents and cabins and presented an appearance of much activity. Toward the south it merges into the broad, grass-covered meadows of Mosquito Fork, where moose are said to have been abundant in the early days. The ridge to the east of the Chicken shows a rather well-defined benching in the vicinity of Mosquito Fork. About a mile east of the Chicken and 275 feet above it there heads a small stream known as the Lost Chicken, which flows southeasterly to Mosquito Fork.

The distance from Franklin to Chicken Creek is about 5 miles. There is a trail which ascends the divide from a point on South Fork just below the mouth of Franklin Creek, and another by way of Franklin and Tin Kettle creeks.

Supplies are brought by freight boats up Fortymile Creek, South Fork, and Mosquito Fork to the mouth of Chicken Creek. There is, however, but little freighting done in summer.

There is an interesting variety of rocks in the valley of Chicken Creek. The igneous rocks may be roughly divided into members of the granite-diorite families, dark hornblende rocks (partly of tuffaceous origin, cut by dikes of the former group), and fresh olivine-basalt. The other rocks include dark shales, much jointed and broken and containing quartz and calcite seams, and a formation consisting of sandstone, sandy shales, and coal beds.

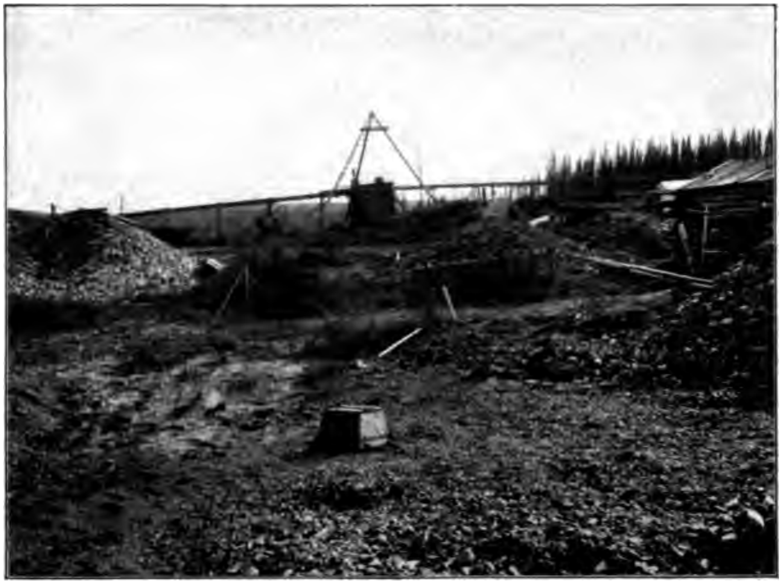
The ridge between Franklin and Chicken Creeks is composed of granular and porphyritic representatives of types ranging from hornblende-granite to quartz-diorite, those related to the latter type being the more common. These rocks also form the canyon wall of Mosquito Fork about 2 miles west of the Chicken, and occur again on the ridge between Chicken and Lost Chicken creeks. The greenstone and related rocks, largely of tuffaceous origin, form the high ridge east of the Chicken and are cut by dikes of the preceding types. Olivine-basalt occurs on Myers Fork, on the lower portion of Stonehouse Creek, and on the east side of the Chicken about a mile below the Stonehouse. It apparently extends over the entire area westward from this latter point to the dioritic rocks on Mosquito Fork. Dark jointed shales with quartz and calcite seams overlie the porphyry east of Stonehouse Creek and are of interest because gold has been found in them. Sandstone, sandy shale, and coal beds occur at several localities on Chicken Creek, and coal is sometimes the bed rock on which the gold is found. The sandstone, the ferruginous nodules which it contains, and the sandy shales all contain badly preserved plant remains, and the formation is correlated provisionally with similar occurrences near Eagle which belong to the Kenai formation.

The stream gravels, so far as known, lie on a bed rock of basalt, sandstone, or coal. They include representatives of the different kinds of bed rock occurring in the neighboring hills. There is a large proportion of greenstone and much olivine basalt; granular and porphyritic varieties of the granodiorite type are abundant, and there is some quartz, slate, sandstone, coal, and ferruginous nodules often containing fragments of dicotyledonous leaves. Pieces of marble and schist indicate the occurrence of a formation like that of Franklin Creek somewhere within the valley. The depth to bed rock in the main valley varies generally from 6 to 45 feet. A layer of muck 22 feet thick covers the gravels, often forming more than half the entire deposit on bed rock. The gravels vary from 6 to 20 feet in thickness and are found mostly on the west side of the stream to a distance of nearly 1,000 feet from it. They vary in size up to a foot or more in diameter, and in the lower portion contain considerable clay, which often acts as a gold robber by balling up in the sluice boxes.

The pay is found mostly on bed rock, but sometimes extends into it and often above it, where it is found through 5 feet or more of the gravel. Most of the work has been done on the west side at a considerable distance from the creek. Pay has been found to nearly the extreme western limit of the gravel and over a width of 80 feet. The values vary from $50 to $175 to the box length, and a considerable portion of the ground probably averages about $1 to the square foot. The gold is different from that of the other creeks. It is usually rather fine, much of it is granular, and the color is generally dark. Some of the gold is rather rough and is frequently found with quartz attached. No large nuggets have been found.

The bench between Chicken and Lost Chicken creeks is about 275 feet above the valley. Ground was located at the head of the Lost Chicken in 1901. Several holes were sunk along the creek and on the bench, and in the last one pay was found at a depth of 33 feet. One hole sunk in the west side of the bench near the top is interesting in that sandstone with plant-bearing shales was found at a depth of 90 feet, overlain by loosely cemented gravels surmounted by 15 feet of muck. In the fall of 1902 some drifting was done on a portion of the ground, which averaged about $1 to the square foot. Near at hand two shafts were sunk to bed rock, one 53 feet and the other 45 feet in depth, and a dump obtained, which was estimated to contain from $35,000 to $40,000. This is shown in the accompanying photograph, taken after $25,000 had already been washed from it (Pl. IX, *B*). The bed rock is of the same dioritic type as that already referred to on Mosquito Fork. The 45-foot hole was sunk to bed rock through 23 feet of muck and 22 feet of gravel and the upper portion of the decomposed bed rock was taken out along with the gravels. These are the same in kind as the recent stream gravels, but are somewhat finer and show more wear. The discovery of gold on this bench has led to much activity in prospecting the benches throughout the region, and considerable work was under way west of Chicken Creek on the high benches of Mosquito Fork.

Chicken Creek has a further interest in that two localities have been found bearing on the origin of the gold. One of these is about 2½ miles west of Chicken Creek on Mosquito Fork. At this point on the north of Mosquito Fork there is a steep canyon wall composed of a medium-grained greenish rock having about the composition of a quartz-diorite. On the side of this canyon wall, about 200 feet above the stream, occurs a mineralized zone, which has a thickness of about 6 feet and a strike of about N. 25° W., in which weathering has produced brilliant red and yellow colors. The rock within this zone is mostly decomposed to a kaolin-like mass, containing abundant fragments of quartz seams. This material pans fine flour gold. Assays of two specimens for the Survey by E. E. Burlingame & Co., Denver, gave for the one, in ounces per ton, gold 0.58 and silver 0.10; for the other, gold 0.36, silver 0.10; or an average of the two of about $9.70 in gold per ton. No drifting has been done and the specimens were taken directly from the surface. The extent of the deposit was still unknown, and as such values would not pay for working under



A. SHAFT AND HORSE HOIST ON CHICKEN CREEK.

B. DUMP OF PAY DIRT ON LOST CHICKEN.

present conditions the occurrence is of interest chiefly in pointing to one possible source of the placer gold occurring on Chicken Creek. This rock is the bed rock on the bench between the Chicken and the Lost Chicken. A porphyry of about the same composition but very different in appearance outcrops abundantly on the south side of the divide between Chicken and Franklin creeks.

On the broad spur east of Stonehouse Creek, about 1 mile north of the junction of the Stonehouse and the Chicken and about 500 feet vertically above it, gold has been found in place in dark shales lying on the nearly flat surface of the fine-grained, dark-colored porphyry to which reference has just been made. At this locality a 10-foot hole has been sunk and a crosscut of less depth run to a distance of 35 feet on the west side. In the bottom of the hole there is exposed about 2 feet of the porphyritic rock, containing abundant corroded quartz phenocrysts up to 3 mm. in diameter, and some larger ones of plagioclase feldspar in a fine-grained, dark-gray groundmass containing some pyrite. This hard, tough rock is considerably jointed and much discolored by iron rust along the joint planes. On top of it is a 10-inch layer of soft black material of the consistency of clay, succeeded by 5 to 6 feet of blackish shales, much jointed and having a general dip of 25° to the southwest, thus conforming with the surface of the porphyry and that of the black layer. These shales contain many calcite and some quartz seams, but these are rarely more than 2 inches in thickness and do not extend into the black layer below them. The quartz seams were found to contain considerable pyrite, and the thinner calcite seams contain interesting specimens of gold, which occurs in thin plates along planes in the calcite. The shales are covered with 2 to 3 feet of soil.

Twelve hundred feet southwest of this locality a similar porphyritic rock occurs, but here the rock is more coarsely crystalline and more like a dark-colored granite in appearance. It was covered with a thin deposit of gravel resembling the bench gravels found at other localities within the valley of Chicken Creek. The igneous rock probably forms the main mass of this broad spur and is overlain locally by the shales. The distribution of the shales and other possible occurrences of gold with them have not been determined. Shales somewhat similar in character are cut by the ditch on the east just above Stonehouse Creek, where they are covered by about 5 feet of muck.

The locality above described has produced many beautiful specimens of gold associated with calcite, and is of present interest chiefly in pointing out another possible source of the placer gold. No work has been done to show whether the shales have been uniformly mineralized over considerable areas. If such were the case and conditions were favorable, they could be stripped from the underlying rock. The water supply in this area is a very limited one.

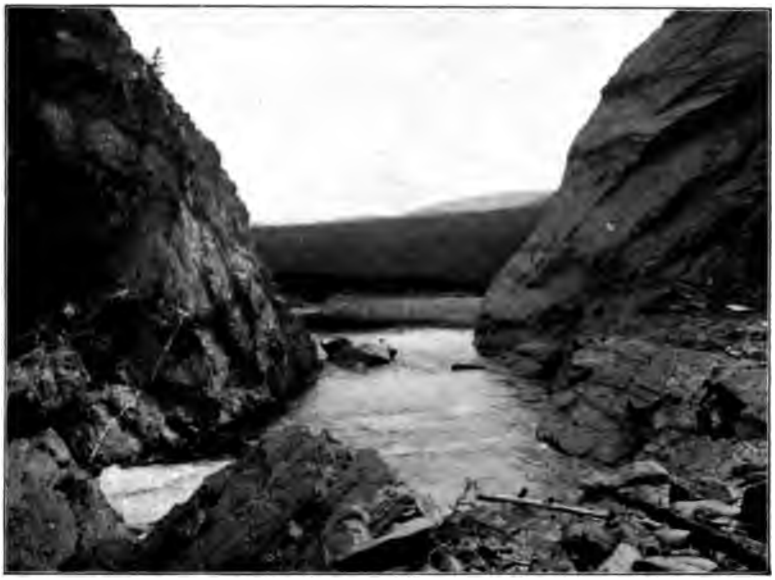
On the main creek methods are in use adapted to the depth and character of the ground, most of the work being done by the steam thawer. Shafts are sunk to bed rock and drifting continued horizontally to the limits of the pay streak, while the dirt is hoisted to the surface in buckets, sometimes by hand windlass, but generally by horsepower or steam hoist. A tripod is erected over the shaft and the rope or cable from the bucket passed over a pulley at the top of the tripod and thence by other pulleys to the source of power (Pl. IX, *A*). Horsepower is cheaper, and with it about 60 cubic yards can be hoisted a day from a depth of 20 to 30 feet. One outfit, by the use of a 12-horsepower boiler steam thawing apparatus and hoist, raised about 80 cubic yards in a day of ten hours from two shafts 45 and 53 feet in depth.

It has been found cheaper to drift in the summer season, for the cost of winter work is about 60 per cent of the output and of summer work only about 40 per cent. The thawed dirt can be dumped immediately into the sluice boxes and washed. There are several miles of ditching to bring water from the various tributaries, but in a dry season the supply is insufficient. In the first week of July, 1903, there had been already three weeks of dry weather and much of the work was at a standstill.

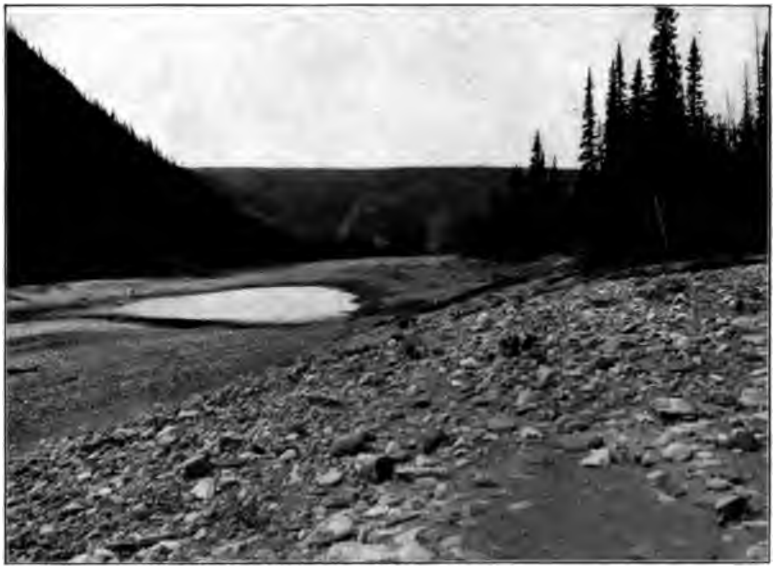
At a few localities on Chicken Creek, Myers Fork, Stonehouse Creek, and Irene Gulch, claims are worked by open cuts. Work can commence May 1 and continue to September 20.

Three claims were being worked on the upper portion of Myers Fork, where the bed rock is olivine-basalt and the gravels vary from 8 to 20 feet in thickness. About 2½ feet of gravels are washed, but most of the gold occurs on bed rock. It is coarser than that on the Chicken and runs from $80 to $100 to the box length.

On the Stonehouse, where a few men were working, the depth to bed rock is about 14 feet, and pay is found through 3 to 4 feet of gravel. On the rim to the east of the Stonehouse the depth varies up to a maximum of about 12 feet. The gold found here is rough and dark colored and may have been derived from the shales cut by the ditch just above this locality that are similar to those in which gold has been found in place one-fourth mile farther east. Irene Gulch enters the Stonehouse from the east. It is very short, hardly more than a sag in the slopes of the main valley, but is interesting in that it also heads in the shale area. The bed rock in the lower portion is sandstone containing nodules with plant remains. Water is brought by a ditch 2,800 feet in length from the upper valley of the



A. ARTIFICIAL CUT-OFF IN SCHIST ON NORTH FORK OF FORTYMILE.



B. BED OF THE NORTH FORK DRAINED BY ARTIFICIAL CUT-OFF.

Stonehouse. Little could be done last season on account of the low water.

The production from Chicken Creek and the benches during the season of 1903 was about $100,000. In July about 80 men were working; earlier in the season there had been perhaps twice that number.

North Fork of Fortymile.—North Fork meanders in a narrow rock-cut canyon about 600 feet below the floor of the old valley. The upstream part and the downstream part of a meander are frequently brought close together and are sometimes separated by only a narrow ridge of rock. In a river like the Mississippi cut-offs are often formed at high water in such portions of the stream, but in a stream like North Fork, deeply sunk within hard rock, a cut-off can be formed by natural processes only when the stream wears away the narrow rock barrier. About 20 miles up North Fork from the junction the two parts of a meander were separated from each other by a sharp ridge of rock over 100 feet high and only 100 feet wide at the base, while the distance around by stream was 2¾ miles. This locality, which is known as the "Kink," lies a few miles west of the area shown on the map (Pl. VII). It was a comparatively easy matter to blast away the rock barrier, and thus form an artificial cut-off which drained the "Kink," with the exception of a few standing pools of water. The original width of the cut-off was only about 15 feet, and at first only a small quantity of water flowed through it, but after a few hours the main body rushed through and soon worked out a channel over 40 feet wide. The low gradient in the 2¾ miles around is now concentrated in a fall of about 17 feet in two portions, an upper one of about 15 feet and a lower one of about 2 feet. There is a deep hole below the falls where grayling swim in great numbers, unable to travel upstream by the customary route or to jump the falls. It is said, however, that the rock is rapidly wearing away, and that even now an occasional fish can make his way to the upper river. A view downstream through the cut-off and another showing the drained bed of the river are shown in Pl. X, *A* and *B*.

The bed rock at the cut-off is quartz-biotite-garnet-schist, with a northwest strike and a northeast dip of 45°. Half a mile to the west occur large outcrops of thin-bedded and massive crystalline limestones with a similar strike and dip. These outcrop on the east side of the hill to the west of North Fork, and the schists occur again on Hutchinson Creek at the saw mill. The same formation of schists and limestones, which is found for several miles to the north and south of North Fork, is a continuation of the formation occurring on the lower Fortymile at Bonanza Bar, Franklin Creek, Wade Creek, and other gold-producing areas. About half a mile above the Kink the schists are cut by a dike of olivine-basalt about 100 feet thick, and

500 feet farther up by another dike of the same rock. The stream gravels are derived largely from the metamorphic formation, but include also a considerable proportion of granodiorite and some basalt. It is proposed to work the gravels in the drained portion of the river bed, which is about 200 feet wide, by a steam dredge during the season of 1904. The gravels along the side of the channel are 7 feet thick and are covered with about 8 feet of sand and muck, while those of the lower benches vary in thickness from 10 to 20 feet. Considerable work has been done here, but it is not known whether the average values of the gravels have been found sufficient to justify their exploitation.[a]

Other localities.—There has been some prospecting in upper Hutchinson Valley. Two men working on Confederate Creek, just above the mouth of Humbug Pup, report about 6 feet of gravel on a bed rock of schist. Some prospecting was in progress on Montana Creek, at the mouth of which good results are said to have been obtained in 1902. So far as seen the bed rock throughout the valley belongs to the schist-limestone formation, cut occasionally by granitic and basaltic dikes.

Napoleon Creek was not visited, but is said to carry good values. It has been extensively exploited in the past, though little except representation work was done during 1903.

A few men were found working on the bars of Fortymile between Steele Creek and Bonanza Bar. The rocks along this portion of the river are closely folded hornblende, mica, garnetiferous and quartzite schists, interbedded with bluish crystalline limestone, with a uniform strike about east and west.

Nugget Gulch, a small tributary of Fortymile, has its source in a dome 3,320 feet in height, about 4 miles north of the river. It flows in a southerly direction through a narrow V-shaped valley, and enters Fortymile about 2 miles below Steele Creek. This creek is said to have produced considerable gold in the early days, but in June, 1903, no one was found working on it. The schist-limestone formation outcrops frequently in the bed of the creek and on the sides of the canyon, with a northerly upstream dip. The quartzite-schists often show crumpling and even brecciation of the different layers. A large mass of basic igneous rock related to gabbro occurs at the head of the creek. The gravels include varieties of schist, limestone, vein quartz, and pieces of the dark-green igneous rock. The creek has been worked for a mile above the mouth, over a width of about 30 feet.

Gravels occur on the benches in the vicinity of the Fortymile, and as the gulch diggings become worked out attention is being directed to these possible sources of gold. The stream which formerly occupied the old valley of the Fortymile had its meanders and deposited its gravels in about the same way as the stream is now doing at a level from 500 to 600 feet lower. As in the present valley only a few localities are found where pay occurs in quantities of economic importance, so in this older, larger valley there were also some localities more favorable than others for the deposition of gold. In prospecting these gravels, then, the form of the old valley, the probable position of the stream within it, its relations to the bed rock, and the lateral spurs and the probable location of the old bars should be carefully studied. The old conditions should be restored so far as possible in the mind of the prospector, and those localities selected for prospecting which seem to have presented in the older time the best conditions for the concentration of the gold.

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[a] No work was done here during the season of 1904 and the locality at present is chiefly of physiographic interest.

Miller Creek is a small branch of Dome Creek about 2½ miles in length, which has its source in the divide between Dome and McKinley, and flows in a southerly direction through a comparatively open valley, bounded on either side by the broad spurs which slope gradually from the divide to Dome Creek. Gold was discovered here in 1893 by men who packed in their supplies from Nugget Gulch. The bed rock belongs to the schist formation and most of the gravel is schist. Pieces are found up to a foot or more in diameter, and a few well-rounded bowlders of quartz of somewhat larger size occur. There are about 8 feet of gravel covered by a variable thickness of muck and moss. The pay, which occurs near the bed rock, in about 10 inches of dirt, over a width of about 20 feet, is said to be mostly coarse and rough, but to include also some smooth pieces. No gold has been found in the other tributaries of the Dome or in the Dome itself, except just below the mouth of Miller Creek, where good pay was found. The locality is interesting in showing an isolated occurrence of gold in a region where there are large areas of similar bed rock.

EAGLE AREA.

American Creek.—At present the most important gold-producing area in the vicinity of Eagle is that of American Creek and its tributary, Discovery Fork. American Creek heads in the divide, about 16 miles southwest of Eagle, flows in an irregular northeasterly course, and enters Mission Creek about a mile above its mouth. From the divide at the source to the mouth there is a fall of more than 3,000 feet. Discovery Fork is formed by the union of several small tributaries, flows in a northerly direction, and joins American Creek within the headwater area. The main stream and tributaries flow, with a swift current, in narrow V-shaped valleys, deep within the inclosing ridges, as shown in Pl. XII, *A*.

Graphitic schists, containing abundant quartz seams, form a portion of the bed rock about the headwaters, and crystalline limestone outcrops on the divide at the head of Discovery Fork. Schists similar to those above described occur again on American Creek about a mile above its junction with Discovery Fork. Below this point to Discovery Fork and on the latter stream, the bed rock is mostly serpentine, frequently cut by basic dikes.

Though American Creek has been worked for several years and considerable coarse gold found upon it, no preparations were made to work the gravels on a large scale until 1903, when a hydraulic plant was installed at a point about 1 mile above Discovery Fork, where there is an ill-defined bench on the west side. The gravels at this locality are about 5 feet thick, composed of schist and igneous rocks. There are 3 feet of loose gravel called "chicken feed," and 2 feet of similar material with a large proportion of clay. Gold is found throughout this lower deposit, but the best pay is next to bed rock, some being also found in the bed rock itself to a depth of 2 feet. Barite is a common associate of the gold.

The slope is a rather steep one, from the edge of which to the water of the creek there is a fall of about 15 feet. A flume, 7,200 feet in length, with a capacity of 1,200 inches, has been built from the upper portion of American Creek, giving a head of 150 feet and furnishing water intended to supply two hydraulic elevators. The capacity of the plant was expected to be about 1,000 cubic yards of dirt in a day of twenty-four hours, and the expense of working about 10 per cent. At the time of the writer's visit the water was turned on the ground for the first time. The plant is a very complete one for work and, if the water supply can be depended upon, should accomplish good results. It is shown in Pl. XI.[a]

Discovery Fork.—On Discovery Fork there are from 4 to 10 feet of gravels lying on the serpentine bed rock, covered with as much as 12 feet of muck. The pay is mostly on bed rock and is rather coarse. Values are found over a width of from 8 to nearly 30 feet. The creek has produced perhaps $20,000. During the season of 1903 two outfits were working on it.[b]

SEVENTYMILE AREA.

Broken Neck Creek.—This creek is about 20 miles northwest of Eagle. It is short, entering the Seventymile from the north just above Mogul Creek, which enters from the south. Its valley is bounded by precipitous walls several hundred feet high, and where

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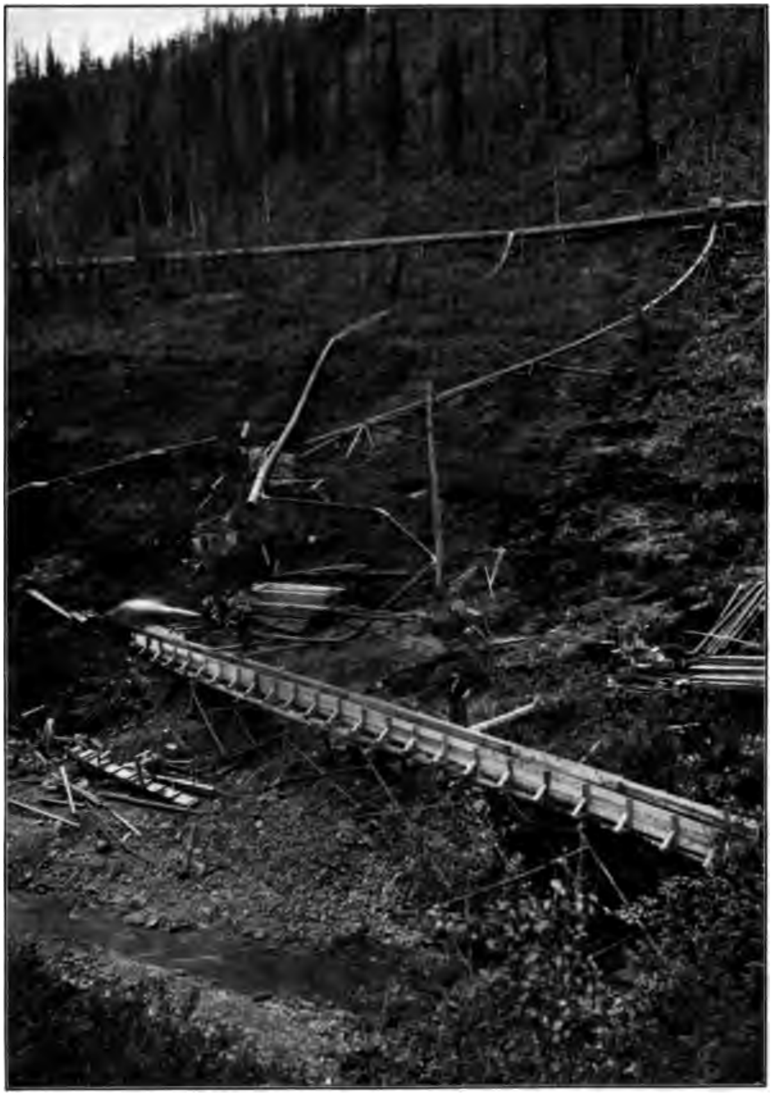
[a] The water supply was found insufficient for the demands of the plant, and during 1904 modifications of the method were being tried to make a more effective use of the available water.

[b] During 1904 excellent results were secured by the use of an automatic dump gate.



HYDRAULIC PLANT ON AMERICAN CREEK.

the stream leaves it to cross the flat to the Seventymile is only 120 feet wide. The bed rock is conglomerate, interbedded with shale containing many fossil leaves of Arctic Miocene (Eocene) age. The strike is N. 60° W., and the dip 75° upstream to the north. The gravels are composed of the pebbles found in the conglomerate, fragments of the conglomerate itself, pieces of shale and sandstone, occasional bowlders of quartzite a foot or more in diameter and unlike the pebbles found in the conglomerate, and bowlders of conglomerate, which are finer grained than that outcropping along the creek, are very compact, and contain a larger proportion of chert pebbles. The creek has been worked to a width of 100 feet at the mouth for about one-half mile upstream. The pay streak is said to have been about 6 feet wide, and the total production about $10,000.

The falls.—The falls are about 20 miles northwest of Eagle, on the Seventymile. Below them the valley of the Seventymile is bounded by conglomerate on both sides; above them for a few miles the river flows close to the contact of the old metamorphic schist formation and the conglomerate; at them the river is cutting the schists and has become separated from the conglomerate by a hill of schist and impure limestone 400 feet high. The falls are only about 9 feet in height. Just below them the stream flows through schist walls 20 to 40 feet apart and 20 feet high. The strike of the schistosity is about N. 75° E.; the dip 25° to the northwest. Folding has been very close, as is shown by the closely appressed minor plications, and the rocks have been much jointed. On the south side of the stream, just above the falls, there is a deposit of gravel on the schist 3 to 9 feet thick, covered with a few feet of muck. At the point where work was in progress the bank is about 10 feet high; a section from top to bottom showed 2 feet of moss and muck, 4 feet of fine gravel and sand, 1 foot of muck and sand, and 3 to 4 feet of gravel. The gravels include conglomerate, schist, vein quartz, limestone, and considerable clay. Pay is said to be found all through the lower gravels.

Three men were working at this locality. A ditch 1¼ miles long brings water from Washington Creek to a point on the opposite side of the Seventymile, across which it is carried in a canvas hose, 8¾ inches in diameter, on a bridge 220 feet long and 30 feet high, to another ditch 400 feet in length, whence it is used (Pl. XII, *B*). During the night the water is run on the muck, sluicing it away, and thus preparing the ground for shoveling in.

Sonickson Creek.—This creek heads in the high ridge about 6 miles south of Seventymile and enters the river about 2 miles west of the fall. In this part of its course it runs close to the southern boundary of the valley, leaving on the north a finely preserved flat a half mile in width and 20 feet above the stream. Sonickson is a small creek, flowing in a canyon whose slopes exhibit well-defined benching in the vicinity of the Seventymile. The bed rock at its mouth is a calcareous and graphitic schist, with a strike N. 80° W. and a vertical dip. Some work has been done near the mouth. The average depth to bed rock is about 8 feet, and the mantle of sand and gravel is about 2 feet thick. The gravels contain bowlders of schist, conglomerate, greenstone, and granite. The gold occurs in thin pieces, which sometimes have quartz attached. At the time of examination little work had been done for five weeks on account of low water.

Barney Creek.—Barney is a small creek entering Seventymile from the north, about 5 miles west of Sonickson Creek and 30 miles northwest from Eagle. It is formed by two tributaries, one from the north and the other from the east, and flows south about a half mile through a very narrow canyon to the Seventymile. The bed rock includes closely folded conglomerate and plant-bearing shales, as on the Broken Neck. The strike is N. 65° W. and the dip varies from 55° south to vertical.

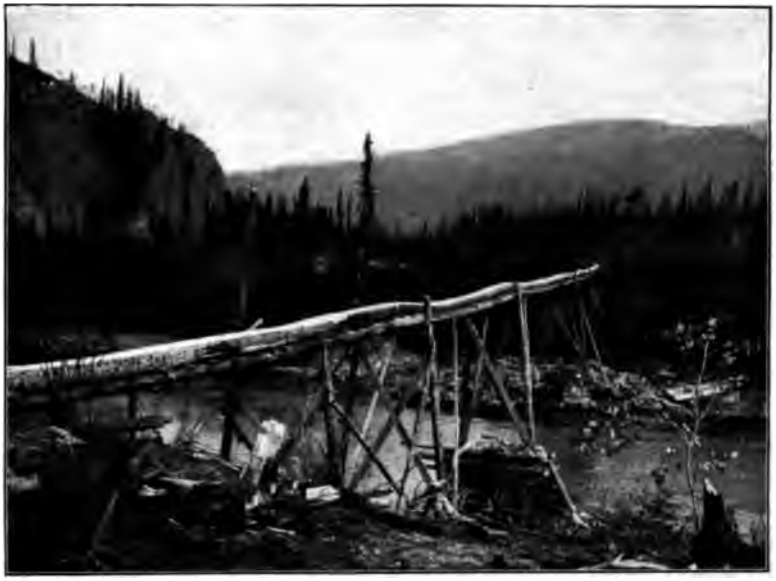
The gravels in the creek are 1½ to 3 feet thick, composed of pebbles from the conglomerate, pieces of the conglomerate, and bowlders of vitreous quartzite up to 3 feet in diameter. The gold occurs in thin plates up to one-fourth inch in diameter.

At a level about 50 feet above the mouth of the creek, on the west side of the stream, and also between the forks about one-half mile upstream, is a deposit about 6 feet thick on the upturned edges of the conglomerate. This deposit consists of 3 feet of gravel and 3 feet of sand and muck. The gravels contain large quartzite bowlders, and on the point between the creeks have been found to carry gold.

The fact that similar bench gravels occur on both Broken Neck and Barney creeks indicates a considerable distribution of these gravels, and the fact that gold has been found in them at Barney Creek points to them as a possible source of the placer gold. The quartzite is entirely massive, vitreous, with no evidence of shearing or schistosity. The nearest locality where similar rock was found in place is on the ridge east of Glacier Mountain and north of Seward Creek. Farther west the ridge south of the Seventymile contains many metamorphosed quartzose sediments and granular intrusives. No evidence could be obtained as to whether gold had ever been found in the conglomerates themselves. The creek was first prospected in 1895, and is said to have been a good producer in 1896.

Nugget Creek.—This creek is small, entering the Seventymile about 10 miles above Barney Creek. The bed rock is a gneissoid granite, and the gravels mostly of the same material, their average thickness being about 4 feet. The gold occurs in plates up to one-fourth of an inch in diameter, and has garnets associated with it. The quantity of black sand is very small. Pay is found over a width of 20 feet from rim to rim and for a length of about four

A. VIEW UP AMERICAN CREEK.



B. BRIDGE FOR CONVEYING WATER IN A CANVAS HOSE ACROSS SEVENTYMILE.

claims. Two men were working on the creek, but could do little on account of the low water.

Flume Creek.—This creek enters Seventymile from the south about 45 miles by trail from Eagle. It heads several miles back in the hills and flows in a V-shaped valley, which about a mile from the mouth becomes very narrow and is bounded by precipitous walls. About a half mile above the mouth the walls begin to recede from the stream, and at the mouth there is a flat about 300 feet in width. A quarter of a mile upstream this is bounded on the west by the face of a rock-cut bench, which lies about 20 feet higher than the creek and has a very even surface mantled with a few feet of gravel.

The bed rock for about a mile above the mouth is greenstone and serpentine. Basic dikes are common. Above this formation are the metamorphic schists. The gravels at this point are mostly schist, but include a considerable proportion of large quartzite bowlders, greenstone, vein quartz, crystalline limestone, black chert conglomerate, and a rock which resembles granite, but is more closely related to a quartz-diorite. The rock is said to occur abundantly at the head of the stream. Flume Creek has been a favorite creek for prospecting. Some coarse gold has been found, and nuggets of considerable value have been reported. There are mineralized areas in the greenstone formation, one of which, hardly a mile above the mouth, has been somewhat prospected. At this place the rock contains many small quartz stringers, intersecting at various angles, and considerable pyrite. The oxidized zone, about 40 feet in width, can be traced across the creek to the opposite wall of the canyon, and strikes about N. 25° W.

Benches.—The extensive benching which the valley of the Seventymile has undergone has been accompanied on the lower benches by the deposition of gravels. Large bodies of these gravels occur, and have been more or less prospected from time to time in the hope of finding extensive deposits sufficiently rich to pay for working on a large scale. Some work was in progress on them during 1903. Prospecting requires much time and systematic work before the values of the gravel can be determined.

In conclusion, it may be said that there are a few of the tributaries of Seventymile that have produced good pay and are still producing a small quantity of gold, and that there are extensive deposits of gravel along the main stream, some of which are known to contain gold, but none of which have had their distribution and values accurately determined. Up to the present time apparently no results have been obtained through the investigation of these gravels sufficient to justify their working on an extensive scale.

About 25 men were working on the Seventymile during the season of 1903.

SUMMARY.

The gold-producing localities of the Fortymile region are divided geographically into three rather widely separated areas, the Fortymile area, the Eagle area, and the Seventymile area.

Through most of the Fortymile area the bed rock belongs to the formation known as the Fortymile formation. It is composed of various schists with interbedded crystalline limestone. All have been closely folded, highly metamorphosed, and intruded by many kinds of igneous rocks. Some of these were intruded so early in the history of the region as to have also undergone metamorphism; others are comparatively fresh. Small quartz veins are numerous, and locally the rocks have become mineralized and are a source of gold. The occurrence on Chicken Creek is different. The bed rock is mostly olivine-basalt and a formation of sandstone, coal, and shale which probably belongs to the Kenai. The walls of the valley are olivine-basalt, granular and porphyritic igneous rocks of types ranging from hornblende-granite to quartz-diorite, and greenstones of the Rampart formation. As the rocks differ from those of the other localities, so, too, there is a difference in the character of the gold, which is generally granular, of a dark color, and suggests a different origin. At two localities gold has been found in place. One of these is outside the valley of Chicken Creek, but in a dioritic rock which is found abundantly within the valley; another is in a shale of undetermined age which may possibly belong to the Rampart formation. The placer gold on Chicken Creek may have been derived mostly, if not entirely, from these two sources.

In the Eagle area the occurrence has not been traced to a source. The bed rock of American Creek near the headwaters is schist and greenstone. In the lower part of its course the creek flows mostly through greenstones and serpentine.

In the Seventymile area also the origin is indefinite. The creeks from the north flow through conglomerate of the Kenai formation. No case is known where gold has been found in place in the conglomerate, but it has been found in a wash containing heavy quartzite bowlders which occurs locally, overlying the conglomerate. No such bowlders were found in the conglomerate, and the wash may possibly have been derived from rather distant sources.

The most interesting recent developments in the Fortymile region are the discovery of gold in place on the Chicken, the working of the high-bench gravels between the Chicken and the Lost Chicken, the draining of North Fork by an artificial cut-off at the Kink preparatory to working the ground on an extensive scale, and the installation of a hydraulic plant on American Creek. The best results so far have been obtained between Chicken and Lost Chicken creeks. About 300 men were working in the region during 1903, and the production was about $175,000.

BIRCH CREEK REGION.

GENERAL STATEMENT.

The discovery of gold on the bars of Birch Creek attracted miners from the Fortymile, and the later discoveries in the gravels of the gulches established the importance of the region and led to its rapid development.

The ramifying headwaters of Crooked Creek occupy a fan-shaped area within the edge of the hills to the south of its broad flat valley (Pl. XIII). On its meandering way eastward to Birch Creek it receives also two tributaries, the Boulder and the Deadwood, which head a dozen miles or more to the southward and flow northeasterly to the main stream in parallel courses about 3 miles apart. The south side of the divide in which these streams head is drained by North Fork of Birch Creek.

The creeks of economic importance on the north side of the divide are Deadwood, Mammoth, Mastodon, Independence, and Miller; on the south side they are the Eagle and its tributary, Mastodon Fork. These creeks were all visited by a survey party in 1896, and descriptions of them by Spurr, Goodrich, and Schrader are to be found in the report of the expedition.[a]

CREEKS.

Deadwood Creek.—This creek, which is about 20 miles long, heads at an altitude of about 3,000 feet, and has a fall of over 2,000 feet from source to mouth. It is divided into two portions, an upper one about 12 miles long, where the stream flows through a rather narrow valley bounded by gradually sloping spurs about 1,200 feet above it, and a lower one about 8 miles long, where the individuality of the valley is abruptly lost in that of Crooked Creek. The fall in the valley portion is about 150 feet to the mile. The stream flat, which attains a width of several hundred feet, is bounded on the east by a rather steep slope, near which the stream flows through most of its course. The west side of the valley shows a more or less well-defined bench, which rises gradually from a level about 20 feet above the stream toward a ridge which separates Deadwood and Boulder creeks. Switch Creek, which is the most important tributary, is about 3 miles in length, flows in a narrow V-shaped valley and joins the main creek about 3 miles above its emergence from the hills.

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[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 342-355.

The bed rock in most of the valley varies from a rather massive, blocky quartzite to a mica-schist. A structure observed at one locality showed a strike N. 60° E. and a dip of 20° to 25° to the southeast. The rocks show evidence of minor folding and contain numerous small quartz stringers. Intrusive granite is very prominent in the region farther east, especially on Ketchum Creek, only a few miles east of Deadwood Creek, where weathering has produced very striking pinnacled forms from this rock in the valley of the creek itself. On Deadwood Creek it is not so conspicuous, but forms the bed rock over a considerable portion of the creek. Dark-colored, more basic rocks occasionally occur.

The gravels are composed of the varieties of rock outcropping in the drainage area and consist mostly of subangular fragments of comparatively small size, more or less irregularly arranged, containing much finely broken material of the same nature. The depth to bed rock varies in the creek from 3 to 12 feet, and on the bench to the west, as far as known from work already done, from 6 to 20 feet. The gravels in the creek vary in thickness up to about 8 feet, and there is generally but a small amount of top dirt to be removed. The values are sometimes found through the whole thickness of gravel, but are generally close to bed rock and are found also in the bed rock to a depth of 2 or more feet. When the bed rock is massive and divided into blocks through jointing, values are found sometimes to a depth of 4 feet along the joint planes. The width over which pay is found varies from about 25 to 300 feet. The average width is said to be from 150 to 200 feet, and the average value of the ground for the entire creek to be about $50 to the box length of 12 by 16 feet. Some ground has averaged much more, values ranging from $100 to more than $200 having been obtained in 1903. Not much work has been done thus far on the bench to the west side of the valley, and little is known of the extent or values of the gravels found there. In a few cases, however, these gravels are being investigated and values have been found. At one locality 20 feet of gravel lie on a rather massive quartzite bed rock at a level of 20 feet above that of the adjacent creek. Little gold is found in the gravel; it is mostly on bed rock and along the joint planes to a depth of 4 feet within it. From something over half a box length of ground, 16 by 12 feet, $128 had been washed, which would give an average for the amount of dirt moved of something more than $1 to the cubic yard. Two nuggets had been found worth $8 and $10, respectively. This locality is important in pointing out the possibility of the extension of the pay over portions of the bench. The creek gold is generally flattened and at the entrance of the valley is rather flaky. The coarsest piece found thus far on the creek was worth $122. That found on the bench is rougher and more

lumpy in character. The present annual production is probably under $50,000; the total production has been about $1,500,000.

Ground is now worked from the headwaters throughout the narrow part of the valley, a distance of about 12 miles, but it was not until 1900 that the lower part was found to be productive. The open-cut system has been employed on most of the ground. It has been found advantageous to work the cuts generally to a width of 16 feet. The depth is such that dirt can be shoveled directly into the sluice boxes. Little drifting has been done thus far on the creek, but it was purposed during the winter of 1904 to work ground on the bench by this method. About 35 men were on the creek at the end of August, 1903. The bench trail from Central House across the flat, about 4 miles, to the entrance of the valley is a good one, but in wet weather that along the creek is soft and difficult to travel.

Mammoth Creek.—Mammoth Creek, which unites with Porcupine to form Crooked Creek, is itself formed by Mastodon and Independence creeks, which unite about 4 miles to the southwest. Miller Creek joins it from the west about 2 miles above its union with Porcupine Creek. About a mile below this last junction it flows through a flat 200 to 300 feet wide, gradually widening as the Porcupine is neared. On the east side spurs descend abruptly from an altitude 1,200 feet above the creek. On the west the valley is bounded by the termination of a narrow spur between Mastodon and Miller creeks, and that of a broad, low spur between Mammoth and Porcupine creeks.

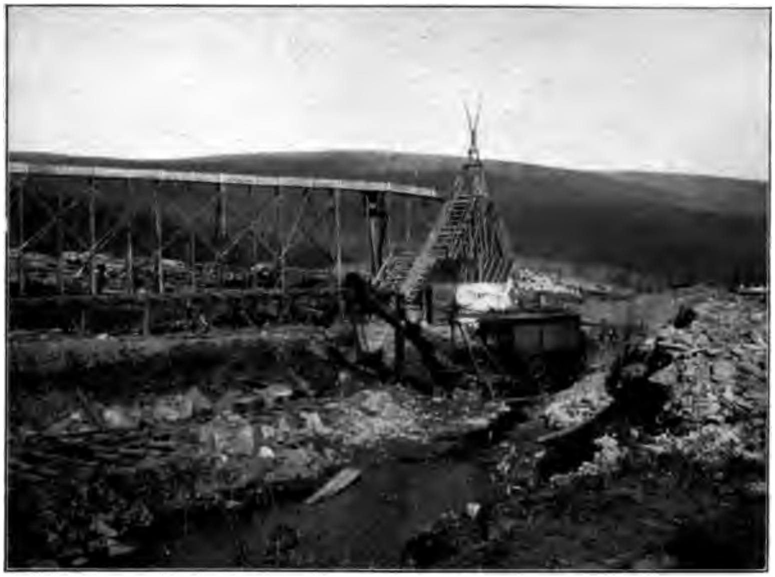
The bed rock is quartzite-schist and granite, and the gravels are made up mostly of these rocks, with a small proportion of vein quartz. The average depth to bed rock is about 10 feet, and the upper 2 or 3 feet are waste. The gold is rather fine, but the ground is probably rich enough to be worked at a profit on a large scale. One of the interesting developments has been the introduction of machinery. A steam shovel, shown in Pl. XIV, *A*, was shipped in over the snow from Circle during the winter of 1903 and gotten into position to work the ground during the following summer. This shovel is capable of handling 500 cubic yards of dirt in ten hours, and has a working width of 26 feet. Twelve hundred feet of track have been provided for it, and there is a face of gravel of about 10 feet upon which to work. The shovel holds about three-fourths of a cubic yard, and the dirt is dumped from it into a car of 1½ cubic yards capacity, which is drawn by cable up a steep grade, a vertical distance of 22 feet, to the boxes. The flume, which has a capacity of 5 sluice heads, brings water from a point 1,700 feet upstream. It is said 3 sluice heads are sufficient for all the gravel the shovel can furnish. The system requires 1½ cords of wood a day and the attention of about 15 men on a shift. A bed-rock drain 400 feet long carries away the water from the cut. Work can be commenced here about June 15 and continued to about September 20.

Mastodon Creek.—The headwaters of Mastodon Creek are gathered from an amphitheatral area on the northern slopes of Mastodon Dome, 4,400 feet high, situated about 7 miles southwest from the point where the creek enters Mammoth. The creek flows through a picturesque valley limited by even-topped spurs, which slope gradually in a direction parallel to the creek at an altitude of about one-fourth mile above it. The valley is unsymmetrical in section, the stream in its lower portion approaching the steep ridge on the east, and being bounded on the west by a bench which rises with a steep grade to the base of the spur. Farther upstream the valley becomes more open and the stream flat attains a width of several hundred feet.

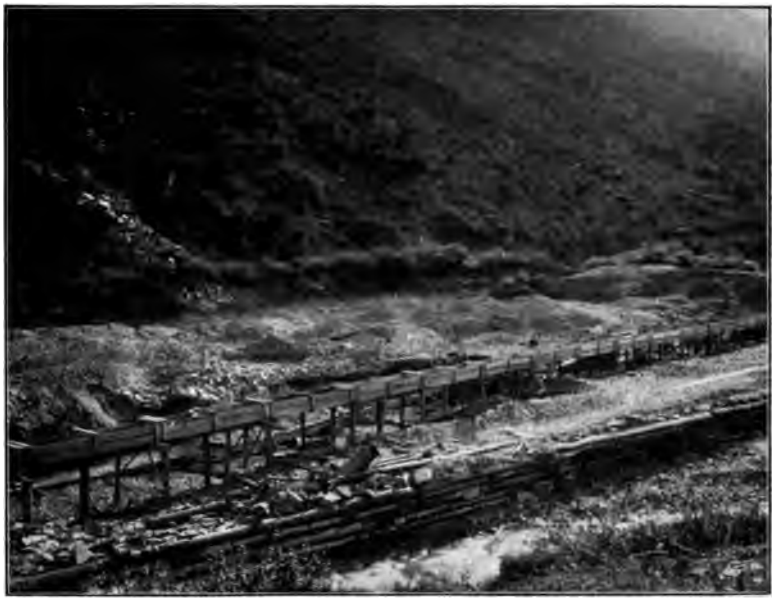
Quartzite-schist and mica-schist are the most common varieties of bed rock and contain the usual proportion of quartz veins. The strike of the schistosity is usually across the stream and the dip to the south. Near the mouth of the Mastodon some thin-bedded, impure, closely folded limestone was observed. On some of the claims occurs a greenish feldspathic schist which weathers more easily than the usual bed rock, and may represent an intrusive rock which has undergone metamorphism along with the other rocks. Small granitic dikes also occur.

The gravels are similar in character to those on the Deadwood. They include subangular fragments of the bed rock, with fine material of the same nature and some sand and clay. A large part of it is but little worn, and the arrangement is generally more or less irregular. The average depth to bed rock is 10 to 12 feet, with a maximum of about 20 feet. There is sometimes a layer of muck on top of the gravels, which attains a thickness of about 4 feet. Seven feet is the maximum of stripping that is required. The gold is found sometimes scattered through the gravel and sometimes close to bed rock or to a distance of a few feet within it. The pay streak has a variable width, with a maximum of perhaps 200 feet. The gold is generally rather fine, the coarsest piece found thus far weighing only 3 or 4 ounces. Some of the ground averages probably from $2 to $3 a cubic yard, and some of it is considerably richer. Estimates of the annual production have been made varying from $75,000 to over $100,000. The gold brings $17 an ounce in trade.

Work, the results of which are said to be satisfactory, is being done on the rim to the west of Mastodon. The gold is somewhat coarser than the creek gold. Portions of the creek have been worked thoroughly and systematically by the open-cut method. At one locality 11 parallel cuts, each 18 feet wide, have been run. (See Pl. XIV, *B*.) It is said to require about twelve days' work of one man to shovel a box length 18 by 12 feet, with an average depth to bed rock of about 8



A. STEAM SHOVEL OPERATING ON MAMMOTH CREEK.



B. BED OF MASTODON CREEK WORKED BY OPEN CUTS.

feet. This makes over 5 cubic yards a day to the man. A strip 2 cuts wide is sometimes worked in conjunction with 2 sets of sluice boxes, and in most cases it is possible to shovel directly into them.

Machinery has been introduced on a few claims. A steam trolley was in use on one claim, by means of which the dirt was raised in a bucket, conveyed along the cable, and dumped automatically into the sluice boxes, which were elevated about 18 feet above the ground. By the use of this arrangement it was said a man's capacity was increased to 12 cubic yards of dirt a day.

On another claim, where there was a depth to bed rock of 8 to 16 feet, a plant was being installed to work by the hydraulic method. There was an 80-foot head of water to be conveyed through the 12-inch pipe to a 2½-inch giant. Everything was to be washed through the boxes, and the tailings raised by steam power to be carried away by water. A combined ditch and flume two-thirds of a mile in length had been constructed, and machinery, consisting of a 20-horsepower double-drum and a 10-horsepower single-drum hoist, had been put in place to elevate the tailings. At another locality the depth to bed rock was about 15 feet, and it was necessary to strip 6 to 7 feet. Machinery was on the ground, consisting of a 20-horsepower boiler, hoist, pumps, trolleys, and scrapers. Part of it was in use and plans were under way for more extensive work.

The season of 1903 was the first in which machinery was used to any extent, and it is yet too early to compare its results with those achieved by other methods. Where machinery had been installed the work was largely experimental, as many of the men were unfamiliar with it, and much time was spent in learning how to get the best results. As there is no wood in the upper part of the creek, fuel had to be brought from Mammoth Creek, and problems in regard to the ownership of timber were already causing difficulty.

There is some winter work done by drifting in the upper portion of the valley, where it is said $20,000 to $25,000 were produced by this method during the winter of 1902-3.

Independence Creek.—This creek also has its source on the northern slopes of Mastodon Dome and flows in a northerly direction, to unite finally with Mastodon Creek. It was not visited, but as far as could be learned the conditions were similar to those on the Mastodon. Seven men were said to be working on it during the season of 1903.

Miller Creek.—Miller Creek is similar in all essential features to Mastodon Creek. It is less than 2 miles farther west, flows northeasterly in a course nearly parallel to that of the Mastodon, and joins the Mammoth about 2 miles above the Porcupine. The stream heads in a picturesque amphitheater of hills. In the upper part of its course there is a bench on the northwest side, and it keeps rather close to the steep slope which borders the valley on the southeast. In the lower valley these conditions are reversed.

The bed rock is quartzite and quartzite-schist veined with quartz. Granitic dikes occur on the divide between Miller and Eagle creeks. The gravels are similar in character and arrangement to those on the Mastodon. The depth to bed rock varies from 8 to 16 feet and there is from 4 to 8 feet to strip. Occasionally there is clay, which has been found to be as much as 3 feet in thickness between the gravels and bed rock. This, when present, contains most of the pay. The gold is about the same as that of the Mastodon. Pieces weighing an ounce have been found, but the general run is rather fine. That near the head of the creek is rough. The gold is found scattered through several feet of gravel over a maximum width of about 50 feet. Some of the ground averages about $1.20 to the cubic yard. It is worked by open cuts, where the average depth to bed rock is about 12 feet, with 6 to 8 feet to strip. It is said that two men can work about 20 box lengths of 12 by 16 feet in a season. Near the head of the creek a month's work may be lost during the summer by low water. The annual production is perhaps $3,000 to $5,000. About 10 men were working on the creek during the season of 1903.

Eagle Creek and tributaries.—All the above creeks are tributary to Crooked Creek. Over the divide from Mastodon and Miller creeks are the headwaters of two small streams, Mastodon and Miller forks, which unite to form Eagle Creek, a tributary of Birch Creek. Gold was discovered on Eagle Creek in 1895, and much work has been done on this creek and on Mastodon Fork. Mastodon Fork heads in an amphitheatral area on the northwest slope of Mastodon Dome, and flows northwesterly through a narrow V-shaped valley for a distance of about 3 miles to Miller Fork. The bed rock and gravels are similar to those on the other side of the divide. As on Miller Creek, clay is often found next to the bed rock of quartzite-schist. The depth to bed rock varies from 8 to 10 feet or more. In some cases there are 3 to 4 feet to strip and 4 to 5 feet of pay dirt. When clay occurs along with the gravels, the gold is often found in seams in the clay a few inches above bed rock. It is also found in the bed rock to a depth of 3 feet. Values are said to occur irregularly on the creek. Some ground has been very good and has yielded from $2 to $4 per cubic yard. The gold is often coarse. A flat nugget was found during the season of 1903 the dimensions of which were 2 by 1¼ inches and the weight 2½ ounces. Some quartz was attached, and the nugget had the appearance of having been derived from a seam in the bed rock. Work has been done on about 1½ miles of the creek, the claims having been worked by open cuts. The creek is said to have produced from $15,000 to $18,000 during the season of 1903.

Eagle Creek has a length of about 4 miles. The valley widens rapidly below the junction of the forks until the valley floor becomes one-fourth mile or more in width, bounded by spurs, which recede gradually as the mouth is approached and terminate in broad low slopes at Birch Creek. Work has been done for about 2 miles below the junction. The bed rock and gravels are similar to those on the other creeks; the depth to bed rock at the localities visited varied from 14 to 18 feet; about 6 feet is ground sluiced, and pay is found in about 6 feet. Values have been found ranging from $125 to about $400 per box length of 12 by 18 feet. Some of the gold is coarse, one piece worth $74 having been found. Work was being done at only a few places on the creek; on one claim a drain was being put in preparatory to winter drifting; at another locality the ground was worked by open cuts, but the depth to bed rock made it necessary to shovel the dirt first to a staging and then to the sluice boxes. The grade of the gold of Eagle Creek and Mastodon Fork is the best found in the Birch Creek region. About 20 men were working on these creeks in September, 1903.

SUMMARY.

The conditions of occurrence on all of the gold-producing creeks of the Birch Creek region are apparently the same. No foreign wash was anywhere observed, and there is no reason to believe that the gold has had other than a local origin. The quartzite-schists contain numerous small quartz stringers, and pieces containing gold in the quartz seams have been found. It seems probable that here is at least one source of the gold. The bed rock, so far as known, is about the same over a large area. Only a few of the streams within this area are gold producers. In a broad way, then, the occurrence of gold shows localization. Whether the rocks have been uniformly mineralized over a considerable portion of the drainage basin of a stream or only within certain zones or areas along its course which are relatively rich is a problem that can be solved only by detailed study. When gold has originated from local rich areas it can often be traced to its source.

The process of distribution, or decentration, as it might be called, of the gold from such local areas through the agency of gravity and local wash precedes that of concentration, and its results may be often obscured or removed by the stream action which brings about the later concentration. It seems probable, in view of what facts we possess, that the gold found on the creeks of the Birch Creek region has been derived from large areas of bed rock more or less uniformly mineralized; that there are probably no zones or pockets especially rich in the metal; and that the distributed products from the areas have been concentrated by stream action modified by localized annual glaciation, or "annual glaciers," as they have been called by Spurr.[a]

About 200 men were working on the creeks, the annual production being about the same as that of the Fortymile region—$175,000.

FAIRBANKS REGION.

GENERAL STATEMENT.

In the rush of 1898 many started for the Yukon from Valdes. Some, after a hard trip, succeeded in reaching the Fortymile region; others, on arriving at the Tanana, chose the line of least resistance and drifted down the river. The economic results were scanty, but some knowledge was gained of general conditions in the Tanana Valley. In the same year a party from the Geological Survey, under Peters and Brooks, descended the Tanana from the headwaters, mapped the area along the river, and studied the geology. An opportunity was thus given to compare the rocks of this region with those of the gold-producing creeks of the Fortymile and Birch Creek regions, studied by Spurr in 1898. The formations were found to be similar to those of the better-known regions, and it is interesting, in the light of recent developments in the Tanana Valley, to read again the following extract from the summary of Brooks's report regarding the possibilities of the region:

> In this description of the gold resources an attempt has been made to state the bare facts, clearly shorn of all speculations and wild rumors. We have seen that traces of gold have been found throughout the region examined by our party, and that the conditions for its occurrence are in many respects favorable; also that the little prospecting which has been done up to the present time has been too hurried and too superficial to be regarded as a fair test of the region. Our best information leads us to believe that the same horizons which carry the gold in the Fortymile and Birch Creek districts are represented in the White and Tanana river basins. I believe, therefore, in spite of the adverse results which have been obtained so far, which are purely negative, that the White and Tanana river basins still offer a favorable field for the intelligent prospector. I am inclined to think that the upper basins of these rivers are occupied chiefly by the younger non-gold-bearing rocks. I should advise prospectors to carefully investigate the small tributary streams of the lower White and of the Tanana from Mirror Creek to the mouth. The headwaters of the streams lying to the north of the Tanana ought to offer favorable returns, situated, as they are, opposite the headwaters of Fortymile and Birch creeks, streams which are more or less gold bearing.[b]

Occasionally men from the Fortymile and Birch Creek regions made short trips over the hills to the south in the early days and did some prospecting in the valley of the Tanana, but trips through this country were necessarily of a hurried nature on account of the distance from sources of supply, and very little thorough work could be done.

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[a] Spurr, J. E., Geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 346.

[b] *Brooks, Alfred H.* A reconnaissance in the Tanana and White river basins, Alaska, *in 1898: Twentieth* Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 488.

A trading post was established in 1901 at the point where Fairbanks is now located, and finally, in July, 1902, gold in quantities of economic importance was found. Felix Pedro, who was prospecting some of the small streams about a dozen miles north of the Tanana and 200 miles above the mouth, found good prospects on the creek which is now called Pedro. Gold was soon found on neighboring creeks and the region became known as the Fairbanks mining district, the name being given in honor of Senator C. W. Fairbanks, now vice-president elect of the United States. The towns of Fairbanks and Chena quickly sprung up on Chena Slough and Tanana River, respectively, and trails were made connecting these places with the creeks. Exaggerated reports naturally found their way to the other camps. People came by way of the river over the direct trail from Circle, 150 miles to the northeast, and by way of the Goodpaster from Eagle, 200 miles in a direct line to the east. The road houses in the Birch Creek region were often scenes of great activity during the winter evenings when men and dogs were gathered from all along the trail. Conditions, however, did not come up to anticipations, and an unfavorable impression of the camp spread up and down the Yukon.

In spite of the unfavorable conditions due to high prices of all kinds of supplies and the lack of ready money for the development of their claims, the men on the creeks kept digging, and by the fall of 1903 the production amounted to $30,000 or $35,000 and the population of the region had become about 800.

The creeks of economic importance referred to under the name of the Fairbanks mining district during 1903 were the Pedro and its tributary, Twin Creek; Gold Stream, the continuation of the Pedro below the Gilmore; Cleary Creek and its tributaries, Wolf and Chatham creeks; and Fairbanks Creek. These all head within a few miles of each other in the divide between Chatanika and Little Chena rivers and flow in divergent courses. (See map, Pl. XIII.)

The Fairbanks district has developed so rapidly that the work of 1903 was supplemented by that of two parties from the Geological Survey during the field season of 1904. C. W. Purington, assisted by Sidney Paige, in the course of detailed studies of the placer camps throughout Alaska and the northwestern British possessions, visited the Fairbanks placers during the later part of July. The writer, assisted by Frank L. Hess, with a packer, cook, and 7 horses, left Eagle June 17 for the Tanana country, traversed the region drained by the Goodpaster, Salcha, and Chena rivers, and reached the Fairbanks district about the same time as the other party.

Many changes were found to have taken place since September, 1903. The town of Fairbanks had become a thriving supply point, the facilities for transportation to the creeks were being rapidly improved, and the production of gold had amounted to at least $350,000. From the opening of navigation on the Yukon, when the party left Dawson on one of the early boats, nearly to the close of navigation in September, all steamers downward bound from Dawson had been crowded with passengers and freight, and during the present winter, 1904–5, there are from 4,000 to 5,000 people in this portion of the Tanana Valley, about one-tenth of whom are employed on the creeks. Naturally, a larger number of people gathered there than the conditions at the time would justify, and along with the workers came an undesirable element to lead a parasitic life upon the miners. It is believed, however, that the Fairbanks district is strong enough in its natural resources to develop healthily in spite of this influx, and the season of 1905 promises to be one of much activity.

The scarcity of supplies and consequent high prices retarded development during the winter of 1903–4, which was a rather hard one for many of the miners. Provisions at Fairbanks and Chena were sold on a cash basis, and a necessary part of the winter's work was the rocking out of sufficient gold from the dumps to pay the grocery bill, which, with flour as high as $30 a hundred, and other things in proportion, was a very important item. Provisions were also obtained as far away as Circle and Rampart and freighted across country. Men were able to buy from one another, and with mutual helpfulness and hard work the time was passed till the boats came again in the spring. Among a few was a spirit of bitterness that things had been as they were, but the general feeling was one of independent cheerfulness. Their resourcefulness was voiced by one of the miners, who said there were too many men handy with the Winchester to go hungry while there were caribou among the hills.

The town of Fairbanks is located along the south side of Chena Slough, upon an extensive flat which affords abundant opportunity for growth. In 1903 a loose collection of log cabins was strung irregularly along the slough and a cable ferry connected the town with the pack trail to the creeks. In 1904 this locality presented a scene of much animation. Warehouses, stores, saloons, and restaurants, either in operation or in various stages of completion, lined the street along the water front, while along the slough, beyond the business portions of the town and over the flat in the background, were scattered the comfortable and tasteful cabins of the inhabitants. Frequent steamers were bringing passengers and freight from the outside, and freight teams and pack trains were loading supplies for transportation to the creeks. The constant hum of the sawmills in town, heard far along the slopes to the north proclaimed the steady growth of the settlement which has sprung to importance on the once quiet flats of the Tanana.

Fairbanks is at present the most important supply point in the interior of Alaska. Transportation from the outside during the last season has been largely by way of Dawson. The largest boats plying on the Yukon transship their passengers and freight at Tanana to boats better adapted to the conditions on the Tanana River.

All of the boats at times of low water are liable to experience difficulty in the slough between Chena and Fairbanks, and some men made good wages during the early part of the past season in poling supplies from Chena to Fairbanks. Supplies are brought also by way of St. Michael, but the fact that boats can reach Fairbanks much earlier in the spring from the upper river has made this route popular at that time of the year, when supplies of all kinds are in greatest demand. Cattle were successfully brought to Fairbanks by being shipped to Dawson, carried thence by scow down the river to Circle, and driven over the trail, a distance of about 150 miles, from Circle to Fairbanks.

The first-class passenger rate from Seattle to Fairbanks during the season of 1904, either by way of St. Michael or Dawson, was $150. The freight rate varies greatly, according to the kind of material; that for ordinary supplies by way of St. Michael was $100 a ton.

A bridge has been constructed across the slough and a wagon road has replaced the pack trail. The wagon road leaves the flat about 2 miles from town, winds with easy grades among the beautiful birches of the lower slopes, and then follows the wooded ridge to a point about 12 miles from town, opposite the mouth of Gilmore Creek, where it descends rather abruptly to the creek. The road from the town to the slope of the Gilmore Valley has required but little work in its construction, and freight wagons drawn by from two to six horses and carrying up to 3,000 pounds of freight find but little difficulty in traversing this portion of it. From here on the conditions are different. There is much soft ground along the creeks, and considerable work and expense are involved in making roads suitable for the transportation of heavy freight wagons. The fact that good roads are possible under similar conditions has been proved again and again on the Canadian side of the boundary, but in the Yukon-Tanana region such roads are not yet in existence. The miner on a claim which is producing only a fair living has no time and little money to spend in combination with other miners in working on roads. It is imperative for him to get as much gold out of the ground as possible during the short season at his command, and the work accomplished on the roads is generally of the intermittent, temporary character which the demands of the moment necessitate. Work was being done, however, on the worst places along the creeks, and by another season the conditions in this respect will probably be improved.

Mining operations which men hesitated to undertake during the winter of 1903–4, on account of lack of supplies, were frequently postponed during the last season to the winter of 1904–5 on account of the bad roads and consequent high freight rates. The rates, however, were reduced somewhat until during the later part of the season the summer rates varied from 10 to 20 cents a pound from Fairbanks to the different creeks. The winter rates are about one-quarter the summer rates.

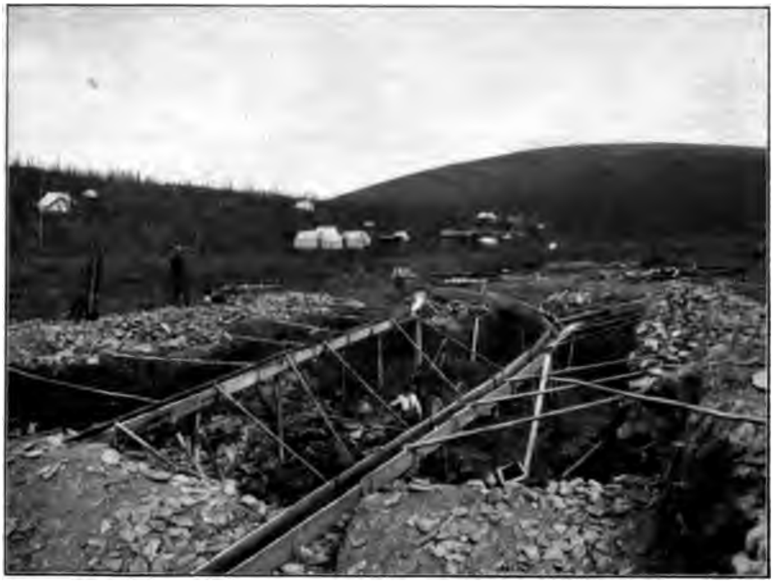
It was reported that material for a railroad, to be built either from Chena or Fairbanks, was shipped in by one of the last boats from Dawson. A road adapted to the conditions could apparently be built quickly and would prove of much benefit.

A telephone line was in process of installation and was reported to be in operation before the end of the season. The work in connection with this project had been done in a very substantial manner. The line was well cleared of brush and timber, the poles were solid and well placed, and when the district was visited the wires were being strung.

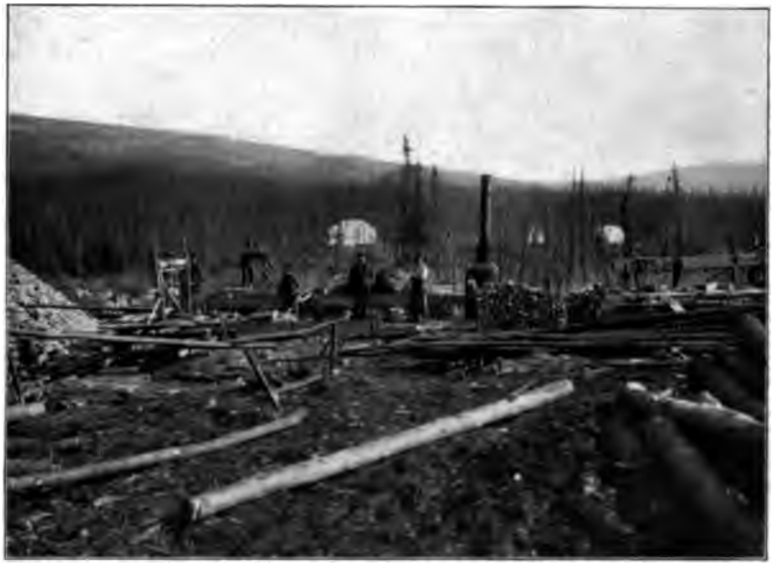
The results attained in the Fairbanks district have stimulated prospecting throughout the Yukon-Tanana region. Gold has been found in widely scattered localities, but not necessarily in quantities of economic importance. Work was in progress above Fairbanks on tributaries of the Tanana from both sides and in the foothills of the southern side of the Tanana Valley 40 to 50 miles south of Fairbanks. A stampede was under way to the southern limit of the Yukon Flats, where prospects had been found on a tributary of Beaver Creek; coarse gold had been found on Ester Creek, a small tributary of the Chena River, about 4 miles from Chena, and a small output was reported from this creek, but production has been confined thus far mainly to the same creeks—Pedro, Cleary, and Fairbanks—which were producing gold in 1903. The following description of these creeks includes only the most general geographic and geologic facts and is concerned chiefly with the economic development.

GEOGRAPHIC SKETCH.

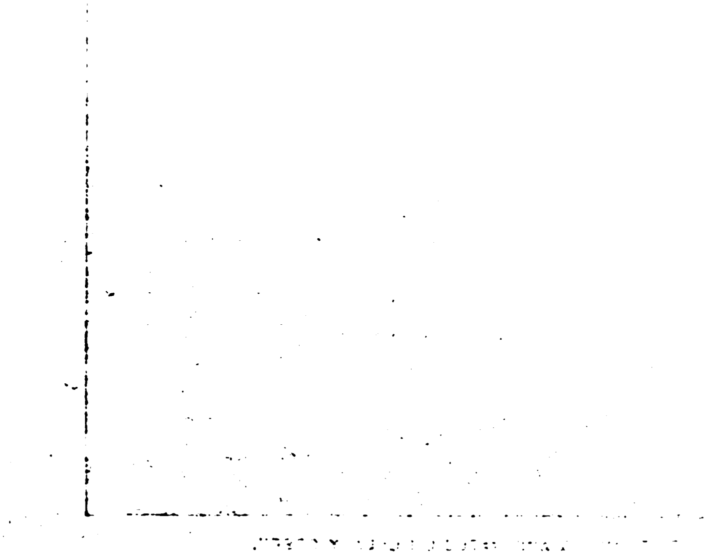
Pedro Creek.—Pedro Creek is formed by the union of small tributaries sunk deeply within the inclosing ridges. The main creek has a southwesterly course, and Gold Stream, its continuation, flows in the same direction for several miles, then bends toward the west and several miles farther joins the Chatanika. The distance from its sources to Gilmore Creek, the most important tributary from the east, is about 8 miles, and the name Pedro is confined to this upper portion. The valley of the main creek is open and has a depth of about



A. SLUICING ON PEDRO CREEK.



B. THAWING APPARATUS ON CLEARY CREEK.



1,000 feet below the ridges which bound it unsymmetrically on either side. The ridge to the southeast is about 2,000 feet above sea level, with short spurs which descend rather abruptly from it to the creek. The ridge to the northwest is about 1½ miles back from the creek; it separates the drainage of the Pedro from that of other tributaries of the Chatanika and culminates in Pedro Dome, 2,585 feet high. Long, broad, timbered spurs slope gradually from this ridge toward the creek and merge smoothly into the valley floor, which is in places developed to a width of several hundred feet. The stream, which is a small one, carrying usually about 200 inches of water, follows an irregular course over a willow-covered surface and has a fall of 100 feet or less to the mile. There are several short tributaries from the west which enter the main creek through narrow valleys, V shaped in cross section. Twin Creek, the most important one, has its rise in the divide which separates it from Fairbanks Creek, and has a length of about 3 miles.

A light growth of spruce, poplar, and some birch suitable for fuel and cabin material covers the slopes, but there is only an occasional tree large enough for mining purposes. Grass grows abundantly on the upper portion of the northwest side of the valley.

The wagon road to the town of Fairbanks leaves Pedro Creek at the mouth of Gilmore Creek; another wagon road follows Gold Stream and traverses the lower country to Chena, on the Tanana River, about 19 miles from Pedro Creek. There are also wagon roads and pack trails to Fairbanks and Cleary creeks. There is a road house at the mouth of Gilmore Creek, and a picturesque collection of cabins, tents, road houses, and saloons is located at the mouth of Twin Creek. The population of this place in 1904 was about 75.

Cleary Creek.—The opposite side of the ridge which bounds Pedro Creek on the northwest is drained by several small tributaries of the Chatanika. The sources of one of these, Cleary Creek, are nearly opposite those of Pedro Creek. Cleary Creek is about 8 miles long; for about 3 miles it flows northeast, then bends gradually to the west and flows in a direction nearly at right angles to its former course, a distance of about 5 miles, to the Chatanika. The creek is a small one, carrying ordinarily from 100 to 200 inches of water; the quantity may vary, however, under extreme conditions from less than 50 to over 400 inches. There is a fall of about 100 feet to the mile in the upper portion of the valley. The valley at the head is rather openly V shaped; lower down there is a gradually sloping bench several hundred feet wide between the stream and the foot of the ridge on the west; below the bend the valley attains a width of 1,000 feet or more before it merges into that of the Chatanika. The stream above the bend flows close to the east side of the valley; below the bend it keeps along the base of the ridge, which here bounds the valley to the south. The tributaries are small and all enter the stream from the east; Chatham and Wolf creeks are the most important. Chatham Creek enters the main stream about two miles below the source; it is a mile long and is formed by two small streams, whose short, steep gulches are in the opposite side of the divide to that drained by Twin and Fairbanks creeks. The creek is straight and flows over a willow-covered flat about 300 feet wide. Wolf Creek heads in the same divide and enters Cleary Creek about a mile below the mouth of Chatham Creek. It is formed by the union of two small, short creeks, which drain an amphitheatral area in the divide, is about 1½ miles long, and flows in a northwesterly direction through an open valley to Cleary Creek. The valley is limited on the south by the steep-sided spur which separates Wolf Creek from Chatham Creek and on the north by a slope which rises gradually to the ridge north of Cleary Creek.

The slopes and portions of the valley of Cleary Creek are covered with a light growth of small spruce and some birch and poplar. In the valley of the Chatanika timber is more abundant and larger than in Cleary Creek Valley. There is fairly good feed for stock high up on the sides of the ridges which face toward the south and east, and on one of these slopes ground was being cleared for early vegetables.

The distance from Twin Creek, on Pedro Creek, to the mouth of Chatham Creek is nearly 5 miles. A pack trail leaves Twin Creek about a mile above the mouth, climbs steeply to the ridge, and follows it to the descent along a spur to the mouth of Chatham Creek. A wagon road more generally used follows a more circuitous course from the mouth of Twin Creek along the ridge on the east side of Twin Creek and reaches Cleary Creek, also at the mouth of Chatham Creek.

There were only a few tents and cabins to indicate the presence of the miner in the fall of 1903. The dull tundra colors of the Cleary Valley were relieved only by the frost-tinted yellow leaves of the willows which line so characteristically the courses of all the streams, but in August, 1904, tents and cabins, thickly grouped where there was most activity, were strewn for several miles along the valley, and indicated in a most graphic way the progress of the year.

Fairbanks Creek.—Fairbanks Creek, which is about 10 miles long, heads in the divide opposite Twin, Chatham, and Wolf creeks, and flows in an easterly direction through an unsymmetrical valley to Fish Creek. It is small, carrying about 200 inches of water and has a fall of about 1,200 feet from source to mouth. The stream flat is narrow and is bounded on the south by a steep slope, broken by a few short narrow gulches, and on the north by broad, rounded spurs, which descend gradually to the creek from the ridge 2 miles to the north. There are several small tributaries from this side which flow in rather open valleys about a mile apart; the most important ones are Moose, Crane, Alder, Walnut, and Deep creeks. The valley widens toward the mouth and merges into the extensive flat of the Fish Creek Valley.

As in the other valleys, the slopes in the vicinity of the stream are covered with small spruce, while higher up there is considerable poplar and birch. The main divides are comparatively bare. Timber for mining purposes has been obtained from the valley of Little Chena River at the mouth of Fish Creek, but the quantity is insufficient for extensive use. Grass is not abundant in the Fairbanks Valley. An extensive settlement has developed along the creek within the last year.

The distance from the lower part of Fairbanks Creek to Fairbanks is about 25 miles. A wagon road has been built around the head of the creek, connecting with other roads to Cleary and Pedro creeks.

GEOLOGIC SKETCH.

The principal bed rock of the region drained by Pedro, Cleary, and Fairbanks creeks and their tributaries is the quartzite-schist of the Birch Creek formation. This varies from a schistose quartzite to a quartz-mica-schist, and contains numerous small quartz seams, which attain a thickness of a foot or more. Thin beds of impure limestone are rarely interbedded with the schists. The structure is complex, like that of the closely folded areas farther north; the strikes are variable and the apparent dips generally low. Gneiss with a well-defined "augen" structure occurs locally in close association with the schist. Hornblende-schist was observed at the head of Gilmore and Cleary creeks and a massive rock composed essentially of hornblende and garnet occurs in the ridge on the south side of Cleary Creek below the bend in association with schist and limestone.

A porphyritic granite forms the bed rock of some of the claims on Twin Creek, and a considerable area of a similar rock occurs along the ridge southeast of Gilmore Creek. A medium-grained granite forms the summit of Pedro Dome, and a finer-grained variety occurs at the head of Chatham Creek.

The schists occur all along the trail to the creeks of the Birch Creek region, and with garnetiferous schists, gneisses, and intrusive granites form much of the country rock to the east of the Fairbanks region drained by the Chena, Salcha, and Goodpaster rivers.

Gold has been found in quantities of economic importance in the schists of the Fortymile, Birch Creek, and Fairbanks regions, and wherever these schists occur they deserve the attention of the prospector. Surface prospects were found by the Geological Survey party during the summer of 1904 on streams which showed no evidences of having been prospected or even staked, and the field for the prospector to the east of the Fairbanks region is still a large one. The study of the older camps emphasizes another important fact which must be borne in mind, and that is that even in a small area where the geologic conditions are apparently the same, the occurrence of gold in sufficient quantity to pay for working may be limited to but a few creeks, and while there is always the possibility of finding workable deposits in the schists of the Yukon-Tanana region, there is no reason for expecting a uniform distribution of such deposits.

On the trail to Rampart the schists were not observed after leaving the ridge which extends along the northwest side of Chatanika River. The country to the northwest is geologically and topographically of a different character and more closely related to the Rampart region than to that already described. The change is indicated by the jagged limestone ridge known as the "White Mountains," which extends in a northeast-southwest direction about 15 miles northwest of Chatanika River.

ECONOMIC DEVELOPMENT.

The present valleys have been formed by the physical and chemical work of the streams aided by the weathering of the rocks. Most of the resultant waste material has long since been removed, but mantling the bed rock of the valleys are unconsolidated deposits composed of rock fragments, of materials derived from rock decomposition and of resistant minerals originally disseminated in small quantities through the rocks. These deposits, accumulated and arranged largely through the agency of water, roughly represent the concentrates from large masses of country rock and within themselves have undergone a further concentration, until the heavier constituents lie on the bed rock or even within it to a depth of several feet along the cracks and crevices. The presence of considerable gold in these deposits has made them of much economic interest and a knowledge of their character, arrangement, and distribution becomes important with reference to the extraction of the gold.

There are several characters common to the stream deposits of all the creeks; the grade of the bed rock on which they lie is gradual; the grade of their surface is about 100 feet to the mile; they are mostly deep and in most localities frozen throughout the year; a section shows generally a layer of muck underlain by barren, and by gold-bearing, gravels; the gravels are composed of about the same kinds of rock, have undergone about the same amount of wear, are of the same degree of coarseness, and are similarly arranged. The thickness of the different layers varies widely and the maximum total depth to bed rock so far as determined by prospect holes is over 80 feet.

Pedro Creek.—The depth to bed rock has been found to vary from 8 to 30 feet, and the deposits show generally the threefold division into muck, barren gravels, and pay dirt. The muck varies in thickness from a few inches to over 20 feet, is made up of decomposed vegetable matter with a considerable proportion of sand and clay, and is matted together and interlaced with roots. Interbedded with it are occasional thin lenticular beds of sand and fine "chicken feed" gravel. The gravels underlying the muck vary from 1 to 20 feet in thickness, but the average thickness in most localities is about 10 feet. They are composed chiefly of quartzite-schist and mica-schist, with some granite, gneiss, and vein quartz. The pieces are rather angular, mostly under a foot in diameter, and there are few bowlders. Much fine material of the same nature is mixed with the coarser fragments and generally the gravels near bed rock are characterized by the presence of a yellow, sticky, micaceous clay, containing minute fragments of schist and quartz. The lower gravels are thus often rather sharply demarcated from those above them, and the fact that the occurrence of gold is limited to this portion of the gravels has led to their designation as the "pay dirt." The arrangement of the gravels, although often irregular, is due essentially to stream action.

The gravels containing the gold vary in thickness from 1 to 4 feet, and gold is also found in the bed rock to a depth of from 1 to 5 feet. The width over which the ground has been found to contain sufficient gold for working varies from 40 to over 200 feet, and in several cases is over 100 feet. The values of the pay dirt vary up to 25 cents to the pan, and much of the ground which has been worked has probably averaged about $1.50 to the square foot of bed rock.

The gold occurs generally as small, flat pieces. No large nuggets have been found, but several were seen ranging in value from $6 to $14; a $19 piece is perhaps the largest that has yet been found. Black sand, garnets, rutile, and iron pyrites are the most common associates.

In the summer of 1902 gold was discovered on Pedro Creek, about one-half mile below the mouth of Twin Creek, at a depth of about 14 feet in sufficient quantity to yield 20 cents to the pan. The work of prospecting spread rapidly up and down the creek and along the tributaries. In the fall of 1903 claims were being worked on Twin Creek, on Pedro Creek from Twin Creek to Gilmore Creek, and below on Gold Stream. In 1904 developments were confined mostly to the main creek between Twin and Gilmore creeks, a distance of about 3 miles. No further work has been done on Twin Creek except near the mouth. Some work has been done on Gold Stream, but no extensive development has yet been undertaken.

Claims are in most cases staked lengthwise of the creek and include 20 acres. They are worked by open cuts and by drifting with steam points.

The ground at the mouth of Twin has a depth of about 12 feet. In 1903 a cut 300 feet long and 18 feet wide had been worked out, and in 1904 the work was continued. The open-cut method was used.

The depth to bed rock on claim No. 2 above Discovery on Pedro Creek is 14 to 16 feet. Eight prospect holes were sunk to bed rock during the winter of 1902–3 by thawing with wood fires, 4 holes being worked at a time, and sunk at the rate of 1 foot per day. Ground sluicing was commenced in June, 1903, and about 4 feet of ground was sluiced off. A bed-rock drain 800 feet long, 1 foot in diameter, and 16 feet below the surface was constructed at a cost of about $1 per foot. Shoveling in commenced about July 20, when most of the ground had become thawed to bed rock, and a cut was worked 120 by 32 feet. Two sets of sluice boxes were used, into which the dirt was shoveled directly as shown in Pl. XV, *A*. The boxes were 12 feet long and 11 by 13 inches in section, and were set with a grade of 7½ inches to the box. The gold was caught in the 4 sluice boxes in the proportion of 16, 4, 2, and 1. A waste ditch had been constructed, and a ditch 1,200 feet long brought water to the upper end of the claim from a small tributary down the creek on the west side. An area 400 by 80 feet was being stripped for work during 1904. The stripping of the muck gives the ground an opportunity to thaw out rapidly in the spring. A 30-horsepower boiler was in use in 1904 to operate a steam hoist, which raised the gravel a distance of 30 feet to the sluice boxes in iron buckets having a capacity of 8 cubic feet. By this method 700 buckets a day could be handled. A mud box 20 inches high, 50 inches wide, and 20 feet long was used. Several steam points thawed the ground in advance of the work of excavation, and a small steam pump was in use to help drain the cut. On claim No. 1 A[a] and Discovery claim preparations were being made in 1903 for future work by the construction of bed-rock drains and by stripping. In 1904 4-horsepower boilers were in use operating as many as 4 steam points with a capacity of about 10 to 14 cubic yards in nine hours. Similar work was in progress on No. 4 below. On Nos. 5 B[a] and 6 B, where the depth to bed rock is about 10 feet, preparations had been made in 1903 to work by open cut. A bed-rock drain 850 feet long had been constructed, but frozen ground had been encountered and the work brought to a temporary standstill. In 1904, however, extensive work was under way both by open cut and by drifting with points. On No. 7 the depth to bed rock is about 24 feet, and the muck is nearly 20 feet thick. The drifting method is employed, and with four points about 12 cubic yards a day can be thawed. On No. 8 B four holes were sunk to bed rock in March, 1903, to depths of 25, 20, 10, and 12 feet. A bed-rock drain 740 feet long was constructed and about 2,000 cubic yards of dirt worked out by ground sluicing and shoveling in. In 1904 work was continued here along the same lines.

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[a] "A" *and* "B" indicate claims above and below Discovery, respectively.

The ground on Gold Stream is 30 feet or more in depth. Work was being done on several claims. Pay is found there, but the results do not seem to have been sufficiently attractive under present conditions to lead to active development. It is probable that as conditions improve considerable work will be done in this portion of the valley.

Wages were ostensibly $10 a day during 1904. The gold, however, was often given a higher value on the creeks than at the stores, where it was accepted in trade at $16 per ounce, and a man would often find his wages had less than $10 worth of purchasing power. The winter freight rate to Pedro Creek averaged about 2 cents a pound; the summer rate during the latter part of the season of 1904 was 10 cents a pound.

Cleary Creek.—Insufficient work had been done on Cleary Creek and its tributaries in 1903 to determine the average depth or value of the ground. It was known to be deep and, in a few places, at least, to carry good values. Since that time the depth to bed rock on Cleary Creek has been found to vary from 14 to over 80 feet. Twenty-nine holes, scattered irregularly along the creek from near the head to within 2 miles of the mouth and laterally to a distance of 600 feet from the creek, gave an average depth of over 50 feet. The material consists of muck, barren gravels, and pay dirt. Muck has been found to a depth of over 50 feet. The gravels, including the pay dirt, have an average thickness of about 20 feet, and, like those of Pedro Creek, are composed mostly of rather angular fragments of quartzite-schist and mica-schist. A considerable proportion of massive hornblende-garnet rock is found in them below the bend. Bowlders are uncommon, but a few of vein quartz up to 5 feet in diameter are found. The yellow clay is generally found in the lower portion of the gravels, where also is found the pay. The thickness of the pay gravels varies from 1 to 7 feet and averages about 3 feet. Gold is also found to a depth of 1½ to 4 feet in the bed rock. The width over which gold is found in workable quantities has been determined in a few instances and is found to vary from 35 to 150 feet. The fact seems to be rather well established that the pay streak is a wide one. It is located on the low bench on the west side of the creek above the bend and below the bend on the opposite or north side of the creek.

There are generally two grades of gold, a flat variety, which occurs in small pieces up to a quarter of an inch or more in diameter and constitutes the bulk of the production, and a coarse variety, which is generally rather well worn and frequently has an oxidized surface. One nugget has been found worth $233. Values in the pay dirt range from 2 to 25 cents to the pan and occasionally run much higher.

Black sand, iron pyrites, garnet, rutile, and a mineral which proved, on being tested by Mr. Hess, to be cassiterite, the oxide of tin, are found associated with the gold.

The depth to bed rock on Chatham Creek varies from 10 to nearly 30 feet. There is but a thin covering of muck on the gravels, which consist mostly of angular fragments of quartzite-schist with a small proportion of fine-grained granite, which outcrops near the head of the creek. The pay gravels average about 3 feet in thickness, and the values do not range as high as on Cleary Creek. Some good ground has been worked, however, and the creek, in proportion to its size, has been a good producer during the past season. The gold is rougher than that on Cleary Creek and is apparently close to its source in the bed rock.

The conditions on Wolf Creek are similar. The depth to bed rock near the head of the creek is about 10 feet. There is little muck and the gravels are composed of angular fragments of quartzite-schist, with some vein quartz. The gold is very rough and gritty, and the occurrence here is interesting in bearing on the origin of the gold from the quartzite-schist, which is the only kind of rock observed about the head of the creek.

In 1903 several claims were being worked on Cleary Creek, notably Discovery claim, and on Chatham and Wolf creeks. Only drifting methods had been used on Cleary Creek, on account of the great depth to bed rock. Open-cut work had been done on portions of Chatham and Wolf creeks.

Discovery claim, on Cleary Creek, is located near the bend, about opposite the mouth of Wolf Creek. A good season's work was done here in 1903. The depth to bed rock is about 18 feet. A 6-horsepower boiler was used to operate 5 steam points, which in ten hours thawed about 16 cubic yards of dirt, which were hoisted by a hand windless to a dump box 18 feet long by 3 feet wide, and washed through the sluice boxes by a stream of water entering from the side of the box. A scrubbing brush was in frequent use to wash the sticky gold-containing clay from the larger rock fragments. At least one sluice head, equivalent to about 50 miner's inches, was required to wash the dirt, and at times during the season of 1903 the supply had fallen short of this quantity. About 600 cubic yards of dirt had been washed from July to September, 1903. The outfit is shown in Pl. XV, *B*. Prospect holes were being sunk on a few claims below Discovery claim. Thawing was accomplished by the use of hot rocks. About three 10-pan bucketfuls were thrown into the holes which were being sunk, and on cooling were shoveled out along with the thawed gravel. Two fires a day were used, and the rate of sinking was about 1 foot to the fire. Only a few holes had been put down above Discovery claim.

Gold was discovered on Chatham Creek in August, 1902. The depth to bed rock at the mouth is only about 6 feet, and an open cut 180 feet long by 20 feet wide was worked out during the season. Claims were being prospected above the mouth, but had not reached the producing stage. Work was being done at a few localities on Wolf Creek by open cuts, and at the head of the creek about 500 cubic yards had been worked over. Most of the ground here required no thawing.

In 1904 Cleary and Chatham creeks were developing rapidly and producing good results. Cleary Creek had developed in both directions from Discovery claim, and from No. 16 A to 13 B, a distance of over 7 miles, the creek and benches were under careful investigation. The ground above Discovery claim for a distance of 2 miles or more is deep, and most of the claims are still in the prospecting stage of development. Most of the work was being done on the low bench to the west of the creek and in some cases at points several hundred feet back from it. Good values have been obtained in some portions of this ground. Development was carried on frequently by small 2-horsepower boilers operating 2 points. Most of the production thus far has been confined to the portion of the valley between Discovery and No. 4 B, inclusive. An important feature is the occurrence of pay not only on the creek but along the base of the hill 400 to 600 feet north of the creek.

On Discovery claim the work of 1903 was continued. The power had been increased, and a steam hoist with 20-pan buckets had taken the place of the hand windlass. A suction pump was used to drain the ground. On the hillside, opposite Discovery, an 8-horsepower boiler operating 5 points had been installed. Two shafts had been sunk 30 feet to bed rock, and the ground was being drifted. No. 1 B had been sold and preparations were being made for work under the new ownership. On the fraction opposite the upper end of No. 1 the the depth to bed rock is 35 feet, and pay had been struck 250 feet back from the creek bed. Work was being carried on in two shafts, and 6 points were in use capable of thawing 150 ten-pan buckets of dirt every ten hours. About 50 inches of water were in use, and the boxes, 10 in number, were set with a grade of 8 inches to the box to wash the clayey gravel. At the upper end of No. 2 B a 5-horsepower porcupine boiler was in use, operating 4 points. The dirt was hoisted 20 feet, and 200 ten-pan buckets were worked in a shift. On the lower part of No. 2 B, with a depth of 40 feet, a plant had been installed capable of handling 100 twenty-four-pan buckets in ten hours. On No. 3 B two holes 40 feet apart had been sunk 38 feet to bed rock, and work was carried on in both at the same time. There is here 20 feet of muck and 18 feet of gravel. No. 4 B has been worked since October, 1903. and has the reputation of being the best producer on the creek. The ground consists of 2 creek claims and 2 bench claims. The depth to the soft graphitic schistose bed rock is 30 feet, and there are 15 feet of muck and 15 feet of gravel. A 20-horsepower boiler, burning a cord of wood every twenty-four hours, furnished the power for the numerous points and the hoist. Two hundred 38-pan buckets were handled a day; they were hoisted 30 feet and run on a trolley 30 feet to the mud box. The boxes were set with a grade of 8 to 11 inches to 12 feet. Twenty men were employed, and wages for miners were $5 a day and board.

Between No. 4 and No. 8 only preliminary prospecting has been done.

From No. 8 to No. 13 work has been done mostly from 300 to 500 feet to the north of the creek. On No. 8 the depth is 52 feet, with about 30 feet of muck. A 20-horsepower boiler was in use, and from 180 to 190 13-pan buckets could be handled daily. The "live water" problem was causing some difficulty and the use of a pump was necessary. A combination ditch and flume brought water to the claim from Cleary Creek. The depth on No. 9 is 50 feet. There is 20 to 28 feet of muck overlying the gravel. Two holes had been sunk and about 30 feet drifted in each. On the upper end of No. 10 the depth is 60 feet; about 20 feet of muck and 40 feet of gravel, 10 feet of which is "chicken feed" gravel. A 10-horsepower boiler was in use. Occasional thin layers of muck in the gravel made trouble, as the muck does not thaw as readily as the gravel. A ditch 1 mile long had been constructed, at a cost of $2,000. On the lower portion of No. 10 three holes had been sunk in a direction crosswise of the bench to depths of 56, 57, and 62 feet. The layer of muck varied from 17 to 22 feet in thickness. The gold here is usually of the finer variety, but a 2-ounce nugget had been found, and it is important to note the occurrence of the coarse gold in this lower wider portion of the valley. A 4-horsepower boiler and 4 points were in use; dirt was hoisted by a hand windlass, fitted with a one-fourth-inch wire cable, and it was possible to handle nearly two hundred 9 and 11-pan buckets a day. On No. 11 bed rock is 70 feet below the surface, and about 80 feet had been drifted. There is 26 feet of muck. Pay had been located on No. 12 about 500 feet north of the creek, where the deposit is over 80 feet thick, consisting of 25 feet of muck, 30 feet of "chicken feed" gravel, and the rest reddish gravel and pay gravel. On the upper end of No. 13 a hole had been sunk 80 feet to bed rock. 400 feet back from the creek, and about 2 miles from Chatanika River. It penetrated 18 feet of muck and 62 feet of gravel, in which some gold had been found. It seems probable that as the conditions of development become more favorable, there may be considerable ground in this *lower portion of the* valley that can be worked at a profit.

Several of the claims on Chatham Creek which were being prospected in 1903 turned out well. Small boilers were in use and the shallowness of the deposits made the cost of working considerably less than on the main creek. Some trouble was experienced with "live water," and on one claim work had been stopped on this account.

The pay gravels in the Cleary Valley are generally at a considerable depth and probably could not be worked at a profit under present conditions for a gold content of less than 5 cents to the pan. The steam-point method is the one most extensively used for thawing the frozen ground, and by this means holes can be rapidly sunk to bed rock at a rate of 3 feet or more a day. The construction of ditches in the frozen muck has been a difficult problem. The grade must be very low, otherwise the water breaks through the frozen muck, and in one instance was seen flowing at a level 15 feet or more below what had been the bottom of the ditch. The presence of ground water has frequently caused difficulty and increased the cost of production to a considerable extent by the extra expense of pumping.

The creek is about 22 miles from the town of Fairbanks, and the winter and summer freight rates are 2½ and 15 cents a pound, respectively. Wood for fuel has been as high as $10 a cord, delivered, and sawed lumber $200 a thousand. Wages for miners were being reduced to $5 and board.

Fairbanks Creek.—The depth to bed rock on Fairbanks Creek increases rather uniformly in a downstream direction from about 15 feet in the upper portion of the area, where development is in progress, to 60 feet or more about 5 miles lower down the creek. The material on bed rock is similar to the deposits on the other creeks. There is an upper layer of muck, an intermediate zone of barren gravels, and, underlying them and more or less distinctly marked by the presence of yellow clay, the gravels which contain the gold. The layer of muck is from 2 to 20 feet thick and often forms about half the deposit on bed rock. The principal rock outcropping in the valley of Fairbanks Creek is the schist, which has furnished the material for the greatest part of the gravels. Quartz seams are rather common in the schist and have contributed their share of the gravels. Gneiss is associated with schist in the ridge south of Fairbanks Creek, forms the bed rock on some of the claims in the lower portion of the valley, and has furnished some material for the gravels. The deposit of gravel occurs to a thickness of 15 feet or more and is composed of rather angular pieces, most of which are less than a foot in diameter. In the lower portion of the valley there is some coarser material, but the proportion of bowlders is small. For over 4 miles along the creek over an area varying from 45 to 250 feet in width, pay has been found in gravel varying from 18 inches to 7 feet in thickness. The gold is similar to that of the other creeks. Coarse pieces are found and these are often in association with much quartz. One nugget has been found worth $190. Values are found ranging from 5 to 10 cents to the pan and occasionally much higher. The creek during the past year has been a strong producer.

Fairbanks Creek was located in October, 1902, but development work on it proceeded slowly, and as late as September, 1903, work was still in the prospecting stage. At that time from No. 15 A to No. 16 B more or less preliminary work had been done, most of it in sinking holes to bed rock. Thawing was accomplished by wood fires, hot rocks, hot water, and steam. Sometimes a combination of hot rocks and hot water was used. In the use of wood fires or even of hot rocks there is frequently a too rapid thawing of the sides. In the hot-water method 20 gallons were used at a time, which in 2 hours would thaw about two-thirds of a cubic yard of dirt. One boiler was in use on the creek, operating 4 points, and two others were about ready to commence work. Hand windlasses were used for hoisting the dirt. Very little sluicing had been done.

The creek presented a far different appearance in 1904. Many boilers had been brought in and developments were active along the portion of the valley from No. 8 A to No. 8 B, a distance of about 2 miles. The creek had passed from the prospecting stage to the producing one. The problems of extraction are similar to those of Cleary Creek and similar methods have been introduced. On No. 11 A the depth to bed rock is 15 feet and the deposit consists of 5 feet of muck and 10 feet of angular gravel. A boiler operating 3 points was in use and the ground was kept free from water by pumping. A ditch 1,200 feet long, 3½ feet wide, and 3 feet deep had been dug to confine the creek so far as possible to the middle of the claim. On No. 8 A there is 3½ to 4 feet of muck and about 11 feet of gravel. The ground was worked by means of a 5-horsepower boiler operating 4 points. Some of the best ground is said to be found along this portion of the valley, and a 10-ounce nugget has been found on this claim. On No. 7 A there is from 2 to 10 feet of muck and 10 to 16 feet of gravel. The gold is frequently coarse and a $190 nugget has been found. There was much activity here and two 15-horsepower boilers were furnishing steam for 20 points. On No. 6 A the depth to bed rock is 19 feet and the material consists of 8 feet of muck and 9 to 10 feet of gravel. A plant was in use capable of thawing about 14 cubic yards of dirt in ten hours. On No. 2 B there is a thickness of 28 feet of muck and gravel in about equal proportions. The plant consisted of a 12-horsepower boiler, points, selfdumping hoist, and a trolley. About 250 thirty-pan buckets were handled in ten hours. The gravel is difficult to wash on account of the clay. Six boxes were in use, including the mud box. They were set with a grade of 10 inches to 12 feet. The mud box and platform were elevated about 12 feet above the ground. Pole riffles were used. A dam had been constructed which raised the water 9 feet and a ditch 900 feet in length brought water to the ground which was being worked. A modification of the steam-point method was in use on No. 3 B. The points were started with water and this was said to greatly reduce the time required in thawing. A pump was used here to elevate about 1 sluice head of water a height of 14 feet. Much work had been done on No. 5 B. The depth to bed rock is 36 feet and pay had been located over a width of 150 feet, partly in the stream and partly in the bench gravels. The gradually increasing width of the valley and depth of the deposit, which on No. 10 B is 60 feet, renders the work more expensive, and development has proceeded more slowly in this lower portion of the valley.

Some lumber had been obtained from the flat at the mouth of Fish Creek, but the supply there is limited. Wood for fuel was obtained from the northern slope of the valley and delivered on the ground. It brought as high as $10 a cord. The distance from the town of Fairbanks to Discovery claim is about 25 miles and the freight rates were about 3 cents a pound during the winter and 20 to 25 cents a pound during the summer.

SUMMARY.

As appears from the descriptions the conditions are practically the same on Pedro, Cleary, and Fairbanks creeks. The valleys are all rather open and sunk to a depth of about 1,200 feet below the ridges. All are limited on the one side by a steep slope and on the other by an indistinct bench of considerable width, and all carry about the same amount of water, which in dry seasons will probably be short of the demand. The growth of timber in all is about the same, and all are dependent on the lower valleys of the larger streams for sluice-box lumber. There is some horse feed along the creeks, and grass grows abundantly on the timbered ridge along the trail from Pedro Creek to the town of Fairbanks, where, in 1903, it was found in good condition as late as September 11. There is good feed in portions of the Tanana Valley, and the agricultural possibilities of the region are still largely untried.

The rock most common on all of the creeks and the divides between them is quartzite-schist belonging to the Birch Creek formation; porphyritic granite and gneiss occur locally; a rock composed essentially of hornblende and garnet occurs on the west side of Cleary Creek. The gravels on all of the creeks are apparently derived entirely from the rocks outcropping in their drainage areas, and the conditions of their deposition by stream action were practically the same. No foreign wash was observed. The gold, too, is found on all of the creeks under about the same conditions. The pay gravels are generally distinguishable from the rest by the yellow, sticky clay which they contain. The gold found at the head of Wolf Creek is very rough and can have been carried but a short distance. It is believed the origin of the gold on all of the creeks is to be found in the small quartz seams which occur generally in the schists; that it has been weathered out from them, and finally become concentrated in the gravels where it is at present found.

The percentage of gold in the gravels and their extent seem sufficient to give the camp a permanence like that of the other placer camps in the Yukon-Tanana region. The depth of the deposit has made development slow and expensive, the cost consuming probably one-third to one-half the output. In this respect the creeks are having a history like that of Chicken Creek in the Fortymile region, which during the past two years has produced about $200,000.

It is impossible for the prospector to accomplish much by rushing hurriedly through this kind of a region. The establishment of stations at different points along the Tanana River where supplies can be obtained has rendered possible the slow, patient work necessary to secure results. Those who have done well in the Fairbanks region are mostly men who have worked hard for several years under the conditions of the country, and the one important point to be kept in mind by those who come into the country for the purpose of prospecting is that gold requires much time, hard work, and expense for its discovery and exploitation.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 251.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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——— Account of an expedition to the vicinity of Mount St. Elias in 1890. In Twelfth Ann. Rept., pt. 1, 1891, pp. 59-61. A full report of this expedition was published in Nat. Geog. Mag., vol. 3, 1892, pp. 53-203. (Out of stock.)

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Map of Alaska, showing known gold-bearing rocks, with descriptive text containing sketches of the geography, geology, and gold deposits and routes to the gold fields. Prepared in accordance with Public Resolution No. 3 of the Fifty-fifth Congress, second session, approved January 20, 1898. Printed in the engraving and printing division of the United States Geological Survey, Washington, D. C., 1898. 44 pp., 1 map. A special publication. The data were brought together by S. F. Emmons, aided by W. H. Dall and F. C. Schrader. (Out of stock.)

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Post, W. S. Cook Inlet, region from head of, to Kuskokwim River and down the Kuskokwim to Bering Sea, Bristol Bay, and a part of Alaska Peninsula; scale, 1:625000. Published in sections in "A reconnaissance in Southwestern Alaska, in 1898." Twentieth Ann. Rept., pt. 7, 1900, pp. 31-264.

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY AND WATER RESOURCES OF CENTRAL OREGON

BY

ISRAEL C. RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GEOLOGY AND PALEONTOLOGY,
Washington, D. C., June 28, 1904.

SIR: I have the honor to transmit herewith the manuscript of a Preliminary Report on the Geology and Water Resources of Central Oregon, by Israel C. Russell, and to recommend its publication as a bulletin.

The report contains interesting and valuable information concerning a little-known region. The field work on which it is based was done under the joint auspices of the western section of hydrology and the division of geology and paleontology. Although it contains a large amount of information concerning the water resources of the region, it is primarily a geologic report, and is therefore offered for publication as a bulletin.

Very respectfully,
C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF CENTRAL OREGON.

By ISRAEL C. RUSSELL.

INTRODUCTION.

ROUTE OF RECONNAISSANCE.

The observations recorded in this paper were made during a rapid reconnaissance from east to west through the central part of Oregon in the summer of 1903, and are in continuation of similar work in the same general region previously done by me, reports concerning which have been published.[a] The arrangement of the matter is geographic, and the audience addressed consists of the people living in the region visited. While my main aim is to indicate where artesian water can be had, I have chosen to present the observations made in this and other directions in a popular form, with the view of interesting those for whom this report is especially intended in the geologic history of the land about their homes.

With Messrs. C. E. Wilson and H. C. Dewey as field assistants, I left Boise, Idaho, on June 28, with the necessary camp equipage, etc., and traveled westward, reaching Burns, Oreg., on July 15. The reconnaissance made by me during the previous summer (described in Bulletin No. 217) terminated on the west near Burns, and the work of the present season practically began there. On leaving Burns the route followed led westward through the western portion of Harney County, across the southeastern and central portions of Crook County by way of Prineville and Sisters, and thence southward through the northwest portion of Klamath County to Fort Klamath. From the last-named place, in order to reach a convenient locality for disbanding my party, the journey was continued westward across the Cascade Mountains to Medford, in Jackson County, a station on the Southern Pacific Railroad, which was reached on September 15.

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[a] Russell, Israel C., Geological reconnaissance in southern Oregon: Fourth Ann. Rept. U. S. Geol. Survey, 1884, pp. 431–464; Geology and water resources of the Snake River Plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 1–192; Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903, pp. 1–51; Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903, pp. 1–83.

Owing to the absence of railroads in the central portion of Oregon, considerable time was occupied in traveling to and away from the region concerning which information was desired. During these parts of the journey only observations of the most general character were undertaken, some of which, however, are set forth in the following pages, as they supplement previous reports.

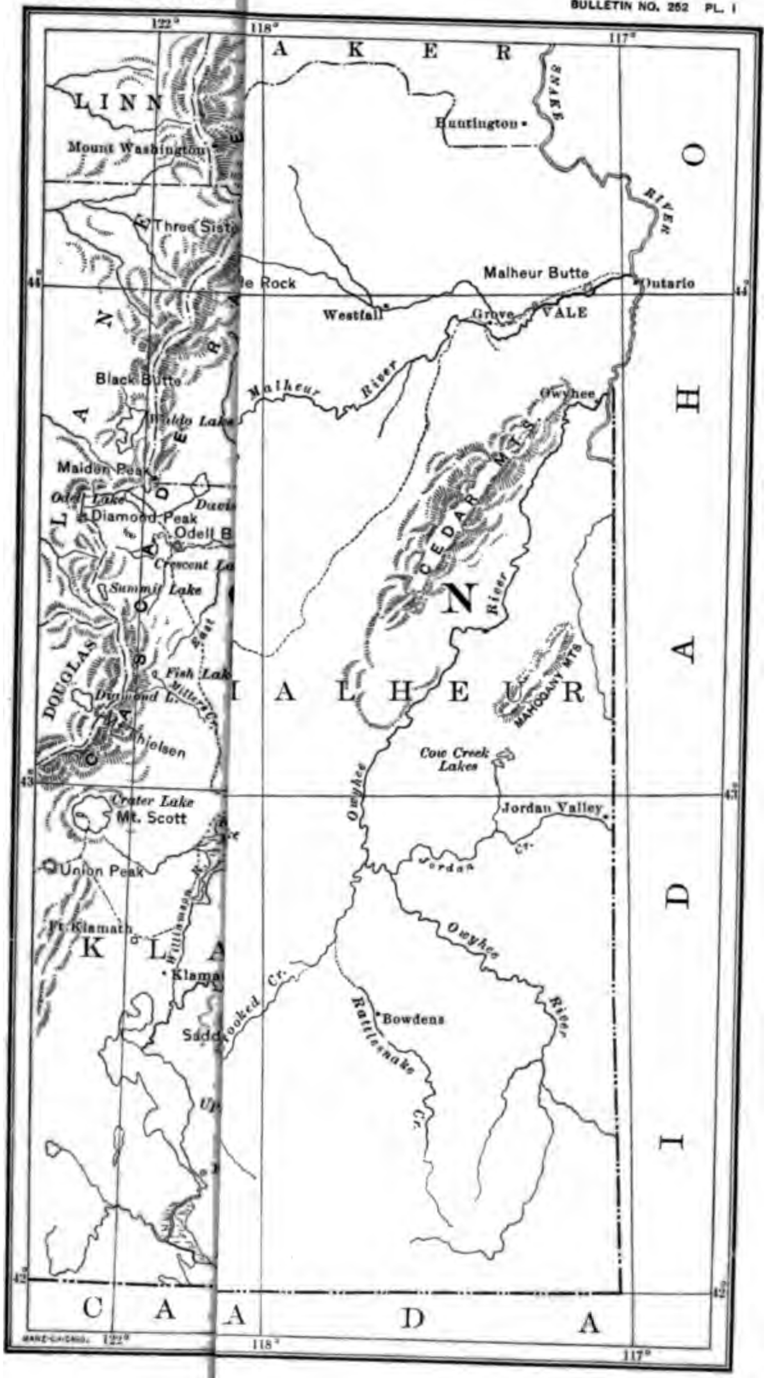
The region to which attention is here invited is indicated on the map forming Pl. I. The portion of Oregon referred to is not only new to geologists (so far as I am aware, no descriptions of its physical features, water resources, or geology are in print), but has not been topographically surveyed. The only map available for use during my reconnaissance was a map of the State of Oregon, drawn to a scale of 12 miles to an inch, published by the General Land Office of the Interior Department. To a large extent this map is devoid of data in reference to even the more conspicuous elements of the relief of the central portion of the State.

The critic who may pass judgment on the value of this report should bear in mind that the observations recorded were made during a rapid reconnaissance through a geologically unknown region, without the assistance of a map showing even the major features of the topography.

GEOGRAPHY.

The part of Oregon under consideration has been briefly indicated above, but its location will perhaps be better understood from a summary account of its relation to the larger features of the drainage of the Pacific slope of the United States.

The region examined includes the extreme northern part of the Great Basin (an area of about 210,000 square miles situated principally in Oregon, Nevada, Utah, and southeastern California, from which no streams flow to the ocean) and a part of the drainage area of Deschutes River and of its principal tributary, Crooked River, which joins it from the east. It lies east of the part of the Cascade Mountains included between Mounts Jefferson and Thielsen, and north of the extensive region in southern Oregon and northern Nevada which was notably deformed by faulting in late geologic time, so as to give origin to several deep valleys, now holding lakes of alkaline water, such as Abert, Summer, Silver, and Christmas lakes. The portion of Oregon and Nevada referred to is unique, owing to the fact that it is a lake region in an arid country, at a distance from lofty mountains.


122°
118°
117°
44°
43°
42°
LINN
Mount Washington
Three Sist
le Rock
Black Butte
Waldo Lake
Maiden Peak
Odell Lake
Diamond Peak
Davis
Odell B
Crescent La
Summit Lake
Fish Lak
Diamond L.
DOUGLAS
Thielsen
Crater Lake
Mt. Scott
Union Peak
Ft. Klamath
Williamson
Klama
Sadd
Up
K L A
C A A
A K E R
Huntington
SNAKE RIVER
Malheur Butte
Ontario
Westfall
Grove
VALE
Malheur River
Owyhee
CEDAR MTS
N
River
I A L H E U R
MAHOGANY MTS
Cow Creek Lakes
Owyhee
Jordan Valley
Jordan Cr.
Owyhee River
Crooked Cr.
Rattlesnake Cr.
Bowdens
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D A
BAKE-CHICAGO

TOPOGRAPHY.

GENERAL FEATURES.

The relief of surface in central Oregon presents well-marked contrasts, ranging from the nearly level, featureless surfaces of the desert valleys, where the general elevation is about 4,000 feet, to the rugged, snow-clad summits of the Cascade Mountains, the highest of which, Mount Jefferson, reaches a height of about 10,350 feet. The contrast between the region extending 150 or more miles east of the Cascade Mountains and the great series of peaks and ridges bounding it on the west is so great that the former region, although actually rugged, seems by comparison monotonous and lacking in variations in relief of surface. But for the overshadowing importance of the great mountains on its west border, however, the central portion of the State would in general be recognized as mountainous.

GREAT SANDY DESERT.

The most extensive tract of nearly level land is situated in the geographic center of the State and is designated in part on the maps as the Great Sandy Desert. This region, termed "sandy" on account of the thick sheet of pumiceous sand and dust that covers large portions of it, extends from the south-central part of Crook County southeastward across the northeastern portion of Lake County and far into Harney County. Its length is in the neighborhood of 150 miles and its width from 30 to 50 miles. So nearly uniform is the surface that one might drive throughout its length, and even for a much greater distance than that indicated above, without meeting any greater obstruction than the rigid sagebrush and—to indicate the aridity of the region—without finding a single watering place for men or animals.

The boundaries of this vast, nearly smooth tract are indefinite, as it is bordered by mountains both of volcanic origin and of upheaval, between which lie the extensive valleys that unite to form the central plain. On the plain itself there are prominent elevations, either standing as isolated buttes or as groups of hills and mountains, which are rendered especially conspicuous because of the general smoothness of the surfaces from which they rise, as well as by the steepness and, in some instances, the ruggedness of their sides.

CLASSES OF ELEVATIONS.

The topographic elevations in central Oregon may be classed in two groups—hills or mountains and plateaus due to upheaval, and hills or mountains produced by volcanic eruptions. Of these two classes the second contains by far the greater number of examples. Each of the groups of land forms referred to as standing in relief may again be divided into those that have derived their most conspicuous characteristics through the action of the forces which brought them into existence, and those that have been modified in an important way by erosion. In other words, there are both old and young hills and plateaus due to upheaval and old and young volcanic cones. These contrasts in age refer mainly to the degree of topographic development produced by erosion, but also indicate in a general way the relative dates at which the various elevations in each class came into existence.

The broad irregular plateaus north of Burns, which extend west to near Prineville, form an uplifted region, perhaps with many minor inequalities, but in general a broad upward swell or anticline produced by upheaval. Its surface has been trenched by streams, but in general is not minutely dissected. About 30 miles south of these plateaus are Powell Butte and the Pauline Mountains, and in the intervening space is a prominent ridge termed locally Pine Mountain. Each of these elements is a remnant of a geologically ancient upland cut down by erosion.

To the east of the central region rise Steins Mountains, a prominent north and south range due to the upheaval and tilting of a large block of the earth's crust adjacent to a line of deep earth fractures—that is, it is a monoclinal or "block mountain." Similar tilted blocks form the prominent, generally north-south, ridges in the vicinity of the alkaline lakes to which Lake County owes its name. These elevations are mentioned because to a great extent they define the boundaries of the less rugged central portion of Oregon traversed during the reconnaissance which furnished the data for this paper, although, in most instances, no fresh information is here presented concerning them.

In central Oregon the most common and most conspicuous elevations are due to volcanic eruptions. In traveling west from Burns to Sisters a few old volcanoes are met in the first half of the journey, such as Placidia Butte, the Glass Buttes, and Hampton Butte, and farther west are seen other ancient craters or much-eroded volcanic peaks and numerous young volcanoes. These young volcanoes are situated for the most part in the northern part of Lake County and the southwest part of Crook County. Their cones, so recent in numerous instances that erosion has not yet broken their crater rims, are so numerous that 50 or more can frequently be counted in a single view, while a change of a few miles in the position of the observer brings perhaps as many more within the range of vision. The cones increase in abundance as the Cascade Mountains are approached, a fact significant of the conditions on which the distribution of volcanoes depends.

The Cascade Mountains border the interior basins and valleys of Oregon on the west, crossing the State from north to south in a continuous belt, which, south of the Columbia, is nowhere intersected by a transverse valley and across which there are no low passes, though at three localities wagon roads have been constructed which furnish routes of travel between the interior of Oregon and the region west of the mountains. The mountains, so far as known, are composed entirely of elevations due to volcanic eruptions, and consist of lava flows and the fragmental products of volcanoes. The eastern border of the range in the portion visited, although well defined, is not abrupt. In the portion of the border between the Three Sisters peaks and Mount Thielsen the recent volcanoes of the interior region extend westward and, becoming more and more closely associated, merge with the volcanic cones which form the Cascade Range. In general it seems to be true that the great number of volcanoes forming the Cascades are situated along a belt of fractures running north and south, from which, at least in the portion of the range between the Three Sisters and Mount Thielsen, branching fractures trend away toward the southeast. Along both the main line of volcanic vents and the extensions from it toward the southeast eruptions have occurred during a long period of time, ranging, as the evidence in hand indicates, from early Tertiary to near the present day. In general the older volcanoes erupted andesitic lavas, while the more recent ones discharged basalt, though marked exceptions to this rule are furnished by certain andesitic volcanoes situated about Pauline Lake, which are among the most recent of the entire region. The most conspicuous feature of the eastern border of the Cascade Mountains is that the range has been built by volcanic eruptions, and only subordinate features of the relief are due to the work of streams and glaciers. This eastern border does not give evidence of being due to a fault or series of faults, as is the case of the corresponding eastern margin of the Sierra Nevada. If a displacement of the basement rocks of the range is present, it is, so far as known, completely buried beneath more recent volcanic ejecta. In no part of the border of the range visited during the reconnaissance here described do the rocks on which the volcanoes rest and through which their conduits were extended appear at the surface. This same generalization, I understand from the observations of others, can be extended to the entire Cascade region in Oregon.

SUMMARY OF TOPOGRAPHY.

In brief, the topography of central Oregon is characterized by the boldness of its elevations, which are due in a minor way to the presence of eminences left by widely extended erosion, but principally to constructive volcanic activity. The valleys between the mountains, buttes, hills, etc., are, in general, level floored, owing in part to the deposition of alluvium brought from the uplands by streams, but mainly to the extensive lava flows and the wide distribution of fragmental material blown out of volcanoes in the condition of gravel (lapilli) and dust. Sheets of basalt which have invaded the valleys and given them level floors, occur widely throughout the central part of the State, and in many localities form the present surface. These lava sheets range in thickness from 80 to 100 feet, as an average minimum, up to probably several hundred feet. In certain localities, as along Deschutes River, in the vicinity of the mouth of Crooked River, the recent basalt rests on stratified lapilli, the revealed thickness of which is about 800 feet. The extent and thickness of these modern volcanic products, both liquid and fragmental, have changed the topography of the land, and, by filling the depressions, have tended to subdue the relief. The valleys, like many of the uplands, are constructional topographic forms.

Later than the spreading out of the deposits just referred to came a heavy and widely distributed shower of pumiceous fragments, ranging in size from dust particles to masses of highly vesicular pumice 2 to 3 feet in diameter, which still remains on the plains and mountains and ranges in thickness up to at least 70 feet. This covering of the land lies on it like a great snowfall, over an extent of several thousand square miles, particularly to the east of the Cascades. It also extends over the mountains and down their western slopes for a score or more miles. It not only has produced many changes in the minor features of the relief, but on account of its extreme porosity is one of the leading factors controlling the agricultural value of the country it covers.

DRAINAGE.

THE GREAT BASIN.

The feature of the surface drainage of central Oregon of greatest interest to geographers is that the Great Basin there reaches its northern limit. The most northern point on the rim of the region of interior drainage is in eastern Oregon, at the head of Silvies River, which flows southeastward and empties into Malheur Lake. To the west of the country sloping to Malheur and Harney lakes the Great Basin divide passes westward through an arid region, where the valleys are broad, nearly level floored, and in large part without stream channels. In the portion of its course between Glass Butte and Pauline Mountain the slope of the surface is so gentle that a careful survey would be required in order to determine where the parting between streams flowing south to some one of the neighboring drainless basins and those flowing north to Deschutes River and the Columbia would be in case precipitation should become sufficiently abundant to form a surface run-off. From the Pauline Mountains southwest to the bold cliffs overlooking East Lake on the east and thence southwest to the Walker Mountains the divide is well marked in the relief of the land, although the deep surface layer of pumiceous dust and lapilli in that region prevents to a great extent the occurrence of streams. South of the Walker Range the divide is irregular, marking the water parting between the numerous streams flowing southwest and south to Klămath and Goose lakes and those flowing north to Silver and Summer lakes. The boundary in the region just referred to is again difficult to determine, for the reason that Goose Lake, although fresh, overflows only during high-water stages. At certain seasons it is to be reckoned as occupying one of the many component depressions of the Great Basin, and at other seasons as a part of the Sacramento drainage system.

The portion of the Great Basin in south-central Oregon comprises the country west of Harney and Malheur lakes and north of Warner, Abert, Summer, and Silver lakes, and also about forty townships northeast of the Glass Buttes. It is practically without surface streams, owing to the small precipitation, the porous character of the soil, and the fissured condition of the underlying lava sheets. The characteristics of the country within the northern portion of the Great Basin and of the region adjacent to it on the northwest are essentially the same. That is, the entire region shares in the same general geologic and climatic conditions; the valleys are occupied for the most part by basaltic lava flows; the surface over broad areas is composed of loose, porous material, largely volcanic dust and lapilli; the rainfall is small; and surface streams are generally absent.

A characteristic feature of the Great Sandy Desert and of the adjacent country, and closely related to the present drainage, is the presence of eroded valleys and canyons disproportionately large in reference to the weak streams now occupying them, and what is even more conspicuous, the presence in several instances of stream channels no longer occupied by water. These features are similar to and, in fact, form a part of the characteristics of the Great Basin and of much of the country adjacent to it, particularly on the north, showing that what is now an arid country was formerly well watered. This is also shown by the well-known greater extent of many of the lakes of the Great Basin region during a former period.

In central Oregon one of the most conspicuous records of formerly greater precipitation, at such a late geological period that the country had its present relief, is furnished by an old river channel, which leads northwest from the vicinity of the Glass Buttes and joins the canyon through which Deschutes River flows. The length of this now streamless channel is about 75 miles. Its course is in the main well defined, and in certain localities, as a few miles north of Pauline Mountain, it is a narrow steep-sided canyon at least 300 or 400 feet deep, cut in basalt. During winter seasons portions of this channel are occupied by running streams, and in summer an occasional water pocket occurs in it, but the inhabitants of the region traversed by it assert that it has never been known to receive sufficient water to form a continuous stream. The reason for the abandonment of the channel referred to does not seem to be solely a decrease in humidity, however, as the lower portion of its course is through a region that has recently been deeply covered with loose volcanic dust and lapilli and crossed by open-textured lava flows. These additions to the surface, which, as will be described later, have caused conspicuous changes in the history of Deschutes River, have also exerted a yet more important influence on this weak tributary.

CROOKED RIVER.

In central Oregon, to the north of the Great Basin and of the adjacent region which slopes toward Deschutes River but has no perennial streams, is situated a rugged plateau drained by Crooked River. This stream, of much importance to the country in which it is located, has its source in a number of copious warm springs about 10 miles east of Hampton Butte, and flows north and west through steep-sided canyons all the way to its junction with the Deschutes, a distance of about 115 miles. In its upper portion, just after leaving the alkaline marsh in which it rises, it receives copious contributions from springs, and in its progress rapidly increases in volume, even in late summer, when there is no surface run-off. It is reported to receive contributions from other springs at various localities along its course until it nears Prineville. Below that town it diminishes in volume, and in late summer its bed near Forest, about 12 miles below Prineville, is frequently dry. This marked decrease is now due largely to the use of the water of the stream for irrigation in the expanded portion of its canyon below Prineville, but under strictly natural conditions it is known to have experienced conspicuous seasonal variations. When the volume of the stream diminishes below Prineville, it exhibits the characteristics common to many streams that flow from the uplands of arid regions and suffer absorption and evaporation as they pass through the lower portion of their courses where springs are absent. Owing to the absence of saturation at any but great depths, percolation is away from instead of toward the stream channels, and such flow as persists becomes tepid, more or less alkaline, and unwholesome.

Another and still more remarkable change occurs lower down the channel of Crooked River, about 10 miles northwest of Forest, where springs of great volume appear in its bed and along its sides.

One of these springs, conspicuous on account of its large volume, is known as Opal Spring, for the reason that in the sands it brings to the surface are kernels and grains of opal, derived from the basaltic rock through which its supplying conduit passes. Other springs come in near at hand, and the river quickly becomes a rushing torrent of clear, cool water. The volume is here about 200 cubic feet per second, practically all of which comes from springs. This conspicuous instance of copious springs rising in the lower course of a river in an arid region finds its explanation in the depth and wide extent of the loose volcanic débris through which the river has cut its present canyon, as will be described more fully in discussing the interesting geology of the Deschutes basin (p. 117).

DESCHUTES RIVER.

The conspicuously arid and treeless portion of central Oregon merges on the west into a less arid region drained by Deschutes River. This fine stream of clear, cool water has its main sources on the east slope of the Cascade Mountains, between the Three Sisters peaks and Mount Thielsen, flows northward, and joins the Columbia about 15 miles above The Dalles. The country it drains is forested and holds several lakes, of which Davis, Odell, and Crescent are the largest. These lakes are exceedingly beautiful on account of the clearness of their waters and the primeval wildness of the forest-covered mountains about them. Owing to the retention of the main tributaries of the river in lakes, as well as the shelter afforded the land by its nearly universal forest covering, which breaks the force of the descending rain, its waters are conspicuously clear. Another and still more important factor leading to this same result is the presence over a large part and, as it seems, nearly the whole of the region drained by the head branches of the river, of a thick surface sheet of pumiceous dust and lapilli. This mantle of porous débris acts as a filter, and the many copious springs issuing from it are clear and cool.

The tributaries of the Deschutes above the mouth of Crooked River come mainly from the west and drain the east slope of the Cascade Mountains. The most marked exception, in reference to direction of flow, is Pauline Creek, which has its source in a lake of the same name, situated in the summit portion of an old and deeply eroded volcanic mountain about 35 miles east of the crest of the Cascade Mountains. The Walker Mountains, also situated well to the east of the Cascades, send some tribute to the Deschutes. The streams just referred to, like the tributaries of the main river from the west, flow over a region deeply covered with pumice, and are clear and cold.

Owing to the efficient filtering the water of the Deschutes receives, and also to the influence of the several lakes discharging into it, which serve as settling basins, its waters are conspicuously clear. It is a swift-flowing stream, broken by many rapids and cascades, where its greenish-blue waters are churned into foam, and is a delight to the beholder on account of its beautiful colors, refreshing coolness, and the frequently picturesque and, in some localities, impressive scenery of its canyon walls, as well as a blessing to the arid region, to which it brings its flood of water for irrigation and other purposes. It is also an attraction to the angler, as its waters are abundantly stocked with trout. Salmon ascend its lower portion, but on account of falls do not reach its upper course.

In addition to the features just described, the Deschutes is of especial interest to geographers, as it exhibits certain peculiarities not commonly met with. Although flowing from high mountains on which precipitation varies conspicuously with seasonal changes and where snow melts rapidly as the heat of summer increases, its volume, throughout a large section of its course, is practically constant throughout the year. From the mouth of Crooked River upstream to Benham Falls, near Lava Butte, a distance of about 50 miles, the variations in the height of the river throughout the year is not more than 8, or perhaps 10, inches where the width is not abnormally restricted. Wooden bridges which cross the river in the portion of its course referred to are placed only two or three feet above its surface during the summer stage, and even the amount of space thus afforded beneath their floors is determined by the height of the approaches and not by the fluctuations in the surface level of the water.

The reason for the practically constant volume of the Deschutes between Benham Falls and the mouth of Crooked River is mainly because it is bordered throughout a part of its course in this section by cellular lava, of recent date, into which its waters flow when a tendency to rise is experienced. This and other instructive features of the river will be described later in this report (p. 117).

CLIMATE.

RAINFALL.

By reference to the general weather maps of the United States, issued by the Weather Bureau,[a] it will be seen that this portion of central Oregon, lying in the northern part of the extensive arid region which intervenes between the Rocky Mountains on the east and the Sierra Nevada and the Cascade Mountains on the west, is credited with a mean annual rainfall of between 10 and 20 inches. While these figures express the average of such weather observations as were available at the time the maps referred to were published, they give a higher average than now seems justifiable. Records kept during the past five years, although somewhat irregularly, at Prineville, Farewell Bend, and Silver Lake, in the central and southwestern portions of Crook County, indicate that the average yearly precipitation in the valleys of that region is about 8 inches.

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[a] Rainfall and snow of the United States, compiled to the end of 1891. Atlas, Bull. C, U. S. Weather Bureau, 1894.

That these records, though meager, do not pertain to exceptionally dry conditions at the points of observation is apparent to one traveling through the section of the State where they were made. Indeed, if there is any exception to be noted, it is in the direction of ascribing even greater aridity to the more sparsely inhabited portions of the county adjacent. Although no weather records are available concerning the Great Sandy Desert, the nature of the vegetation, and especially the absence of juniper trees over vast areas, as well as the lack of streams and springs, indicate that it is more arid than the country about Prineville, Farewell Bend, and Silver Lake, where junipers thrive. This conclusion needs to be qualified, however, by the recognition of the fact that both the Great Sandy Desert and the region adjacent on the west are covered to a depth of many feet, in places fully 50 feet, with a layer of pumiceous gravel and dust, which permits the quick descent of surface waters.

But even after giving due consideration to the influence of the physical condition of the soil on vegetation it is apparent that the controlling element of the climate of central Oregon is aridity. The small amount of annual precipitation falls principally during the winter months and largely in the form of snow. A notable fact in reference to the rainfall is the strong contrast between the arid country at the east base of the Cascade Mountains and the well-watered higher peaks of that range, which are white with snow throughout the year, and which descend on the west into a decidedly humid region. Farewell Bend, for example, with a mean annual precipitation of about 7 inches, situated on the Deschutes River near Pilot Butte, at an elevation of approximately 3,700 feet, is only about 20 miles east of the snow fields on the neighboring portion of the Cascade Mountains, and not over 100 miles from the coast region of Oregon, where the mean annual precipitation is 70 or more inches.

TEMPERATURE.

Owing to the dryness of the air both the daily and yearly range in temperature is great. On the broad desert-like valleys in summer the thermometer, which frequently registers 100° F. or more in the shade at noon, drops so rapidly in the evenings, owing to the active radiation, that the nights are cold and occasionally marked by frost. In winter the temperature frequently drops to zero or lower and the skies are prevailingly cloudy, though only a few inches of snow lies on the ground for any considerable time.

WINDS.

There are at least two features of the weather of west-central Oregon that should repay careful investigation because of their bearing on interesting climatic questions and on the former distribution of glaciers. One is the absence, so far as I have been able to learn, in the vicinity of the Cascade Mountains of what are termed "chinook winds," which are of the same nature as the foehn winds of central Europe. These winds, as is well known, are warm, drying currents of air which blow during the winter months and cause a rapid melting, or rather evaporation, of the snow, if any be present. The localities where these winds occur are lowlands or valleys on the leeward side of high mountains, across which the air currents move. The accepted explanation of the warmth and dryness of chinook winds is that the air in passing across a mountain range parts with some of its moisture, which falls as snow, and on descending into adjacent valleys is warmed by compression and in consequence of its increase in temperature has its capacity for moisture increased. It would seem that the topographic conditions in west-central Oregon adjacent to the east base of the Cascade Mountains are most favorable for the production of such winds, but the inhabitants of the region, many of whom are familiar with the nature of chinook winds elsewhere, report that they do not occur.

RELATION OF CLIMATE TO ANCIENT GLACIERS.

The second suggestion in reference to the climate of the region in central Oregon to the east of the Cascades is what seems to be an abnormally low mean annual temperature for its geographic position and its elevation above sea level. This suggestion is not based on accurate observations and would perhaps not be worthy of mention if it were not that glaciers during recent geologic time (Pleistocene) had a surprisingly great development in the same section of the State. The existence of some relation between the former extent of glaciers and the present distributions of precipitation and of temperature has been shown. In this instance, however, what is now a cool, arid region was formerly occupied by extensive glaciers. The study of the two phenomena together might result in instructive conclusions in reference to the causes of glacial conditions.

FORESTS.

DISTRIBUTION.

In reference to the distribution of trees over central Oregon and the relation of the species of trees present to climatic and soil conditions, the portion of the State visited presents marked contrasts.

The magnificent forest, principally of pines, firs, and cedars, which clothes the part of Oregon situated west of the Cascade Mountains extends eastward across that range, with but little change in its general characteristics until the valleys of the west-central part of the State are reached, in which locality a decided change begins.

The Cascades are forest-covered on both their east and their west slopes up to an elevation of about 8,000 feet, and, as comparatively few peaks rise above that height, nearly the entire range is dark with evergreens, but few bare cliffs or crags being visible. The few great peaks that do rise above the general crest line of the range, like Mount Hood, Mount Jefferson, the Three Sisters peaks, Bachelor Mountain, Diamond Peak, and Mount Thielsen, are covered with perpetual snow, except where the slopes are precipitous. This forest has been invaded by lumbermen to only a slight extent and, barring the destruction due to fires, nearly everywhere recognizable, still retains its natural wildness and pristine beauty.

On the east side of the mountains the forest, while it descends to their base and advances into the adjacent arid valleys, exhibits a change due to a decrease in humidity. Firs, sugar pines, and cedars, which occur on the slopes of the range, do not appear in the valleys. The yellow pine, however, which is the most abundant tree on the eastern side of the range, and which has adapted itself to a wide range of climatic and soil conditions, forms an open forest which extends well into the arid portion of central Oregon, including the southwest part of Crook County and the adjacent portions of Klamath and Lake counties, reaching nearly to Christmas Lake, and covering the Pauline Mountains, which are situated 50 miles east of the crest of the Cascades.

Beyond the frequently sharply defined eastern limit of this widely distributed species is a still more open growth of juniper trees, which in turn die out in the valleys where the soil is light and porous and the precipitation meager. East of these barren valleys of central Crook County, junipers, succeeded on the higher lands by yellow pines, again appear and extend southeastward across Lake County and far into Harney County.

The table-lands and low, broad mountains in the region drained by Crooked River and farther eastward, reaching nearly to Burns and Harney, are clothed with a fine forest of yellow pine. The forests on both the west and the northeast border of the treeless central part of Oregon are not only extensive, but contain magnificent, well-grown trees, which will be of great commercial value when railroads shall have been built, which will bring them within reach of markets. The lumber resources of Oregon to the east of the Cascades are immense, but owing largely to the surprisingly small extension of railroads in that portion of the State but little seems to be generally known concerning its timber resources. It is fortunate that these great forests have escaped the demands of industry so long, as large portions of them have now been included in national forest reserves and can be utilized under the supervision of skilled foresters, so that their continuance is assured.

DEPENDENCE OF FORESTS ON WATER SUPPLY.

The striking contrasts seen in central Oregon in the distribution of trees may be indicated by describing briefly some observations made from a few of the more commanding mountains and isolated buttes that were visited.

One of the most conspicuous landmarks in the eastern part of this field is Placidia Butte, situated in Harney County, about 8 miles from its western boundary, in the midst of the vast tract of arid land that extends westward from Harney Lake. Placidia Butte is an old basaltic volcano, the crater of which, if one ever existed, has been broken and defaced by erosion until only a single sharp summit remains, appearing as a cone when observed at a distance from any point of view. The butte has an elevation of 700 to 800 feet above the neighboring plain and gives from its top an unobstructed view over a great extent of country. On looking southeastward the eye ranges over a basaltic plain which descends gradually until, at a distance of 20 miles, the white salt-incrusted shore of Little Silver Lake is seen, beyond which the bare summits of Iron Mountain and other and more distinct elevations south of Harney Lake can be distinguished. There is not a tree on the vast stony plain. In fact, with the exception of a few dwarfed junipers on adjacent ridges, not a tree can be distinguished within the field of view, although the dark shading on the mountains to the north is due to the presence of the forest of yellow pines that covers the hills and table-lands to the northwest of Burns. The landscape to the west is far extended, but is also barren and lifeless, with here and there depressions containing small ephemeral water pockets, the shores of which are white with saline incrustations. Far away, at a distance of about 145 miles, gleams the white conical summit of Mount Jefferson. To the southwest, shutting out from view the Cascade Mountains in that direction, are Pauline and Walker mountains, situated well within the arid region, but, on account of their height, dark with forests. To the south many ruddy hills are in sight, but they are bare of all vegetation except the ever-present sagebrush and its usual associates on arid plains. Bunch grass is abundant, but, owing to the almost total lack of water in summer within a radius of a score or more miles, the pastures are but little utilized.

The general characteristics of the country, which are conspicuous to an observer standing on Placidia Butte, pertain also to the region in view from the summit of Glass Buttes, situated 20 miles to the west, and again to that seen from the top of an old companion volcano, known as Hampton Butte, which rises from the adjacent sagebush valleys about 15 miles still farther to the northwest. Each of these prominent and deeply stream-sculptured mountains has a height of approximately 1,500 feet above the adjacent plains, and each bears groves of pines on the shaded northern slopes of its steep ridges, but for the most part only sagebrush, bunch grass, and their usual associates on its other portions. While the forests of the plateaus and mountains to the southwest of Burns are in sight from the summit of Hampton and Glass buttes, and while dark areas, like the shadows of clouds, mark the sites of open growth of gnarled and aged junipers on the desert plain to the west and south, the far-reaching landscape everywhere bears evidence of the dearth of water. The Glass Buttes rise boldly from a barren plain, and to reach them by the most favorable route one must traverse at least 12 miles of nearly flat sagebrush-covered land. This statement, however, does not convey an adequate idea of their isolation, as the watering places throughout the region are wide apart and in most instances are but small openings in the sands in which the diminished extremities of brooks have sunk into the soil. The few watering places, separated by wide intervals, in the surrounding country are well known to the residents of the region, and can readily be found by the stranger by following the well-beaten trails, but one might travel in a straight line almost in any direction from the buttes for distances of 40, 50, or more miles without discovering a flowing stream or a spring. So desolate is the country and so widely scattered are the few places where water can be had that even experienced "cowboys" in attempting to traverse it have in some instances become lost during storms and have nearly perished from thirst.

Few localities in the continental portion of the United States present to view a greater extent of mountains or offer for study a more interesting assemblage of topographic forms than may be beheld from the summit of any one of the many isolated volcanic cones and craters which rise from the sagebrush valleys and broad desert plains of central Oregon. These elevations also afford excellent localities for observing the distribution of trees. The dark forest mantle which clothes the entire Cascade Range with the exception of its higher spires and more lofty craters may be seen descending their eastern slopes and extending far out on the lower and less rugged country adjacent to their well-defined base, ending in an irregular line in the shadeless valleys. The conditions favoring or opposing the growth of trees are there delicately balanced, and each variation in the nature of the soil, in elevation, or in position in reference to the mountains finds expression in the tints of the vegetation. Adjacent to the base of the Cascades and within what may be termed their rain shadow, the hills and valleys alike are dark with forest trees, which lessen the sharpness of the relief of the land. Farther eastward elevation becomes the controlling factor, and only the hills and the isolated mountains have a forest covering, the valleys being broad expanses of russet brown and gray, the characteristic colors of sagebrush lands. Farther from the great mountains only the summits of the higher elevations support trees, which, in such localities, are in many instances confined to the northern or shaded and consequently less arid slopes of peaks and ridges. Well within the arid region even prominent hills are without vegetation of higher growth than the all-embracing sagebrush.

DRY AND COLD TIMBER LINES.

To an observer, where the desolate plains of central Oregon are in view at the same time with the near-by snow-covered mountains, the fact of there being a "dry timber line"—a definite limit to forest growth determined mainly by lack of the requisite moisture—is fully as apparent as is the existence of a "cold timber line," dependent on the low mean annual temperature and the destructive action of winter storms, etc., in the higher mountains. The recognition of these two principal limitations to forest growth furnishes convenient terms by which to designate the chief boundaries of arboreal vegetation in such regions as central Oregon, where the forests terminate abruptly both above and below. On the Cascade Mountains, in the region referred to, the cold timber line has an elevation of about 8,000 feet, while the dry timber line, marked by the cessation of the yellow pine, may be taken as approximately 4,000 feet. The junipers reach lower and extend farther into the broad arid valleys than do the pines, but even when most abundant can scarcely be considered as forming true forests. They also, however, have a lower or desertward limit, determined mainly by decrease in soil moisture, which is in advance of or below what may justly be termed the dry timber line.[a]

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[a] The terms cold timber line, dry timber line, and another, the wet timber line—convenient names by which to designate the three most conspicuous natural boundaries of forests—were proposed by me in the Nat. Geog. Mag., vol. xiv, pp. 80, 81, and were used also in Bull. U. S. Geol. Survey No. 199. Objections to the recognition of the names referred to, and especially the substitution of cold timber line for the time-honored term timber line, have been presented by Dr. C. Hart Merriam in the Nat. Geog. Mag., vol. xiv, pp. 114, 115. While it is true, as stated by Merriam, that the word timber line is widely current in the sense just stated, yet other limitations to the distribution of forests are fully as conspicuous in certain regions and demand recognition. The several conditions which determine the boundaries of forests seem to make it desirable to employ the term previously used to designate one of them, in a generic sense, and to recognize "species" of timber, or perhaps better, tree, lines. This matter is also briefly discussed in the Nat. Geog. Mag., vol. xv, Jan., 1904, pp. 47-49.

GENERAL GEOLOGY.

The rocks of eastern and central Oregon belong to two general classes, volcanic and sedimentary, the former being the more abundant and, so far as surface outcrops are concerned, by far the more conspicuous.

VOLCANIC ROCKS.

The rocks of Oregon which were derived from volcanoes are mainly rhyolites,[a] andesites,[b] and basalts.[c] In each of these three classes, as defined by chemical and mineralogical composition, there are two conspicuous subdivisions based on the physical condition of the material at the time of its extrusion from the earth's interior. One of these is composed of fragmental products blown out by volcanoes during explosive eruptions, such as volcanic dust, volcanic gravel or lapilli, and the other of lava flows. The fragmental material was discharged in a solid condition, and the lava flows in streams of molten rock.

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[a] Rhyolite; name derived from a Greek word meaning to flow; given to a certain group of rocks which owe their origin to the consolidation on cooling, with more or less complete crystallization, of certain of the material discharged from volcanoes in a fused condition. Rocks of this group usually present subdued shades and tints of red, brown, purple, yellow, gray, etc., and frequently have a banded structure as if composed of many thin, irregular layers, which show variations in color and texture. The edges of the layers, when seen in section, usually appear as irregularly curved bands and lines, or what is termed "flow structure." The most abundant minerals present, and the only ones usually visible to the unaided eye, are quartz and the variety of feldspar having the appearance of clear glass, known as sanadine. Rhyolite contains in general about 74 per cent of ~~alumina~~ silica and several other oxides of the alkaline earths, etc., in smaller proportions. As indicated by its high per cent of silica, the rocks of this class are difficult to fuse, a fact which has an important bearing on the forms the lava assumes on cooling and also on the shattering of the rock during eruption so as to form fragmental products.

Rhyolitic tuff is composed of angular fragments, grains, and dust-like particles of rhyolitic lavas which were blown out of volcanoes during explosive eruptions and showered on the adjacent land or water, so as to form beds or sheets. The beds of this material are commonly more or less consolidated and not infrequently sufficiently compact to be used as building stone, although in many instances they retain their original incoherent condition and are simply loose gravel, sand, and dust. Their colors have as wide a range as those of the associated rhyolitic lava sheets, although perhaps in general more decided; in sunlight they frequently appear brilliant. Both rhyolite and rhyolitic tuff are common in central and eastern Oregon. The latter is used as a building stone at Burns.

[b] Andesite; named from the Andes Mountains; is typically a compact, usually rough and porous rock, in which crystals of feldspar and small scales of mica, hornblende, etc., may be detected by the unaided eye. The colors are usually some shade of gray, green, or red. In chemical composition the andesites are poorer in silica than the rhyolites, the percentage ranging from 56 to 70, and are also richer in alumina, the next most important constituent, which ranges from 14 to 19 per cent, the remainder of the material present being for the most part as oxides of other alkaline earths. The rock is refractory, and during explosive volcanic eruptions is frequently blown out in fragments.

[c] Basalt; name dating back to the days of the Romans; now used to designate certain common rocks of volcanic origin, usually black or greenish black, though frequently red, owing to a higher state of oxidation of the iron present. The rock seldom exhibits individual minerals to the unaided eye, although grains and kernels of bright green olivine are not uncommon. The essential minerals are augite, plagioclase, feldspar, and olivine in the normal variety, together with several accessory minerals. Although variable in composition, silica usually forms about 55 per cent, and alumina, lime, magnesia, and oxides of iron and manganese from 7 to perhaps 14 or 16 per cent each. On account of the easy fusibility of several of the constituent minerals the rock melts at a comparatively low temperature and becomes highly liquid. Basalt in the condition of broken fragments is less common than in the case of rhyolites and andesites, and the chief products of the volcanoes from which it is extruded take the form of lava flows. The black, compact, and frequently columnar rocks of central Oregon are mostly basaltic.

In general the rhyolites and andesites of central Oregon are older than the basalts. Certain andesites and andesitic tuffs, however, like those described later as occurring about Pauline Lake, are among the youngest of the lavas outpoured in the entire region. Again, in the west-central part of the State and including a part at least of the Cascade Mountains, there is, as already mentioned, a surface sheet of pumice, composed of angular fragments that were showered on the land during the explosive eruptions of neighboring volcanoes, and that now mantle the surface like a blanket. This material is in large part a highly scoriaceous or froth-like andesitic lava, and shows that volcanoes discharging such material were in a state of vigorous eruption in west-central Oregon at a recent date.

SEDIMENTARY FORMATIONS.

In addition to the volcanic rocks which cover the greater part of the surface of Oregon there are areas hundreds of square miles in extent which are occupied by soft and in part unconsolidated sedimentary beds of Tertiary age. These beds consist of clays, sands, volcanic dust, etc., are mostly light colored and frequently white, and in general are best exposed in the valleys and in the walls of canyons. The sedimentary beds of Malheur and Harney counties are in part a direct continuation of the extensive Payette formation, so admirably exposed along Snake River in southwest Idaho. Similar sedimentary beds occur in the southeastern part of Crook County, as at Logan Butte, near Price, and are a part of a widely distributed formation which is well developed on John Day River, from which it has been named.

These Tertiary sedimentary formations are in many places covered by sheets of basalt, or by layers of consolidated rhyolitic tuff which have protected them from erosion. Where the resistant, covering beds have been cut through by streams, canyons with rim rocks either of basalt or of rhyolitic tuff are a conspicuous feature in the topography. The sedimentary beds occur mostly in the valleys, for the reason that when exposed without a protecting cover of more resistant material they are readily removed by erosion, and thus give origin to depressions. Yet in certain instances, and especially in reference to the John Day formation, extensive movements in the rocks have occurred and the beds have been elevated so as to form plateaus in which the component layers are now inclined, commonly at angles of 10° to 15°.

GENERAL SURFACE DISTRIBUTION OF ROCKS.

In Malheur and Harney counties rhyolite and rhyolitic tuff are the most common of the surface rocks, though basalt of later age has a wide distribution, while rocks of a similar character but older than the eruptions which supplied the rhyolite and with a thickness of at least 5,000 feet are admirably exposed in the east-facing escarpment of Stein Mountain, as previously reported.

To the west of Harney County, and extending to the east base of the Cascade Mountains, basalt predominates, although much eroded andesitic mountains or buttes and widely extended sheets of tuff of the same general nature are present. The old volcanic piles are represented by the Glass and Hampton buttes, and the sheets of rhyolite, and the still more abundant and more widely spread sheets of rhyolitic tuff, form the surface in the southeast part of Crook County and extend eastward into the northern part of Harney County. Basalt occupies the surface throughout nearly all of the region bordering the Great Sandy Desert and throughout the extensive tract of country in the western portion of Crook County drained by Deschutes River. To a conspicuous extent, as shown in the canyons of the streams, it occurs in comparatively thin sheets resting on lacustral deposits or beds of stratified volcanic tuff. The canyon walls are margined above by black cliffs or rim rocks of basalt forming the eroded margins of sheets which in general are 80 to 125 feet thick. The basalt occurs as widely extended sheets, usually, it is presumed, of Tertiary age, which can not be traced to the craters from which they came, and also as much later flows of a similar character, which in part occupy canyons cut in the older basalt and underlying gravels, sands, and tuffs, and in many instances bear a definite and determinable relation to volcanic craters which still preserve their constructional forms.

FEATURES OF THE REGION, BY COUNTIES.

MALHEUR COUNTY.

GEOLOGY AND TOPOGRAPHY.

PAYETTE FORMATION.

The Payette formation, which consists principally of unconsolidated sands, clays, gravel, etc., together with important beds of light-colored and frequently white volcanic dust, and which is widely exposed in southwest Idaho, extends westward into Malheur County, Oreg., where it forms a large portion of the surface. This formation was crossed during my reconnaissance in 1902, and again in 1903, but its entire extent in Malheur County, can not, as yet, be stated. It occupies the Snake River Valley, from near Owyhee northward beyond Ontario, and extends westward to a locality about 30 miles southwest of Vale. Similar beds occur also along the courses of Jordan and Succor creeks, and in several other valleys. As exploration progresses it will probably be found that many of the valleys of Malheur County are floored to a depth of several hundred feet with soft unconsolidated deposits like those of the Payette formation and probably of the same or of approximately the same age. Whether all of these deposits are portions of one continuous formation, or were laid down in separate and contiguous basins, is not as yet determined. It is probable, however, that they were accumulated in much the same manner that beds of like character are now being spread out on the surface of the valleys of the same region by existing streams. In most of the sediments referred to as being analogous to the Payette formation, however, volcanic dust added materially to the depth of the deposits.

At Ontario a well put down by the city reached a depth of 1,056 feet, all in soft material, without reaching the bottom of the formation. The surface portion of this deposit is clearly a part of the Payette formation, and it is presumed that the entire depth of the well is in the same formation. But even the considerable thickness of soft material shown by this boring does not give the original thickness of the Payette formation, since at least several hundred feet of similar material has been removed by erosion from the surface of the region referred to. The material removed has been carried away by Malheur River, along which sloping gradation plains, as they are termed, lead down to Snake River, the master stream of the country. The Snake has also cut down its valley, the material removed having been carried through the magnificent canyon it has excavated in its course across the rugged country where the Seven Devils and the Powder River Mountains are located.

From the broad plain through which Malheur River flows, and about midway between Ontario and Vale, there rises a conspicuous and picturesque landmark known as Malheur Butte. This in general conical elevation with precipitous sides rises, as determined by aneroid measure, about 500 feet above the adjacent portion of Malheur River, and from its summit commands a view of a far-reaching and instructive landscape. Geologically it is composed of dark basic volcanic rock resembling basalt (determined by F. C. Calkins as basalt containing hypersthene), compact and massive at the base of the butte, where it is penetrated for a short distance by a tunnel excavated for the passage of an irrigation ditch, but vesicular at the top, and containing oval cavities due to the expansion of steam in its material while it was yet plastic. These cavities are now in part occupied by infiltrated siliceous minerals. The butte is probably the much-eroded remnant of a volcanic crater. Associated with the basalt are small exposures of sedimentary beds, hard and compact, which have the appearance of having been baked by the heat of the molten rock which came in contact with them. The sedimentary beds still clinging to the sides of the butte indicate that several hundred feet of similar material have been eroded from the region about it, thus leaving it as a prominent topographic feature. The interpretation of these facts seems to be that a volcanic conduit was extruded upward through a thick deposit of sedimentary beds, presumably belonging to the Payette formation, and built a crater above. Erosion has since removed the crater and cut deeply into the stratified sediments which its conduit penetrated, leaving the rock, which hardened in the conduit, standing in bold relief as a so-called "volcanic neck."

From the top of Malheur Butte the light-colored rocks of the Payette formation may be seen outcropping in every direction. On the east side of Snake River, to the north of Ontario, the strata dips southward for a long distance at a low angle, probably less than 2°, showing that the formation has been broadly upraised and tilted. Similar evidence of movements in rocks of the same nature and probably of the same formation can be detected in other directions. As shown by this and other related evidence there have been considerable and widely extended movements of the nature of broad uplifts, and perhaps of equally broad subsidences, between the various upraised regions since the Payette beds were deposited.

The nature of the rocks composing the Payette formation, the conditions under which they were deposited, whether in lakes or in streams, the records of life they contain, the deformation their beds have experienced, the erosion that has taken place in them, whether due to their own upheaval or to the deepening of the canyon of Snake River farther down its course, and the local geology about Ontario, Malheur Butte, Vale, etc., all furnish material for study that would yield much interesting and instructive information.

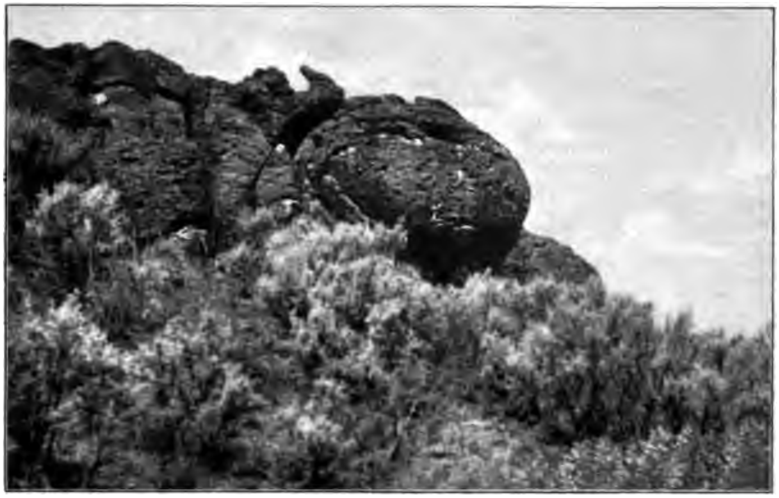
VOLCANIC ROCKS.

A few miles south of Grove the topography changes conspicuously. The broad valley excavated in soft rocks gives place to bold and in part rugged uplands, through which the Malheur and its tributaries have cut deep canyon-like valleys. These uplands, beginning near Grove and extending far to the south, are composed largely of rhyolite and rhyolitic tuffs, in part at least of older date than the Payette formation, and associated with extensive sheets of basaltic lavas. In the walls of the canyons well-defined rim rocks are conspicuous, beneath which are less resistant beds, probably of sedimentary origin, or of the nature of volcanic-dust deposits, presumably belonging to the Payette formation. The resistant layers are of volcanic origin, and their gentle dip to the north is evidence of broad, widely extended movements in them since the material of which they are composed was spread out. More than a general idea, however, of these widely extended terraces could not be obtained during my rapid survey.

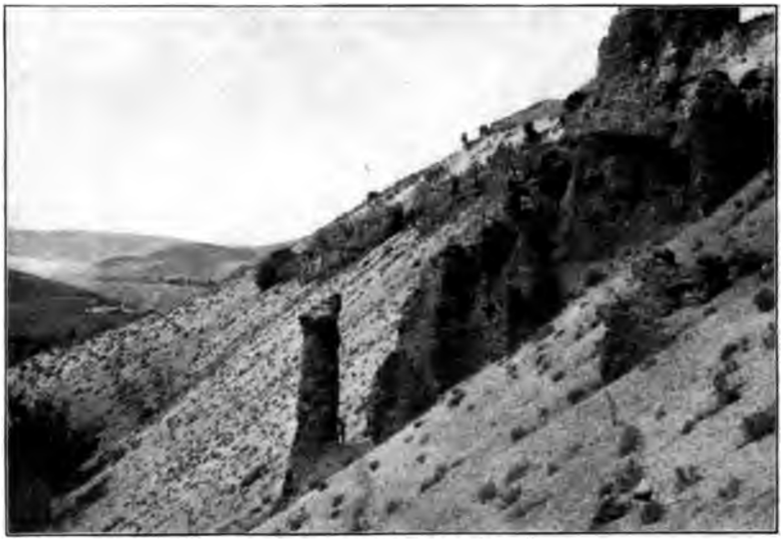
Volcanic dust.—A representative example of the geology of this portion of Malheur County occurs in the vicinity of what is known as Harpers Flat, situated on the Malheur about 30 miles southwest of Vale. At this locality the river has excavated a valley about 2 miles wide in soft, unconsolidated sand and clays which contain a large proportion of white volcanic dust. Some of the layers of nearly pure volcanic dust are from 20 to 100 feet thick. Sections of these beds are exposed at many localities in the precipitous walls of the valley beneath rim rocks of basalt. A roughly measured section on the eastern side of the valley, about 1 mile south of the narrow canyon at the northern end through which Malheur River outflows, contains in vertical section about 650 feet of soft stratified beds, consisting principally of white volcanic dust overlain by a sheet of basalt 25 to 30 feet thick. Similar sections are more or less well exposed all about the valley. At numerous localities, particularly on the precipitous northern border, landslides have occurred, giving to the bluffs the characteristic features of landslide topography.

A conspicuous characteristic of the fine-grained shaly layers which occur at different horizons in the soft deposits about Harpers Flat is that they have been indurated, probably by the infiltration of silica through the agency of hot percolating water, and have the physical characteristics of white or gray flint or chert. The débris from similar beds occurs at many localities in the northern portion of Malheur County. The sedimentary and tuff beds beneath protecting sheets of basalt are also exposed along the creeks which join Malheur River near Harpers Flat, and present a wide range of variations in appearance and composition. In certain localities, as on Willow Creek 4 to 5 miles from its junction with the main stream, the beds exposed on the sides of the valley consist largely of dark volcanic tuff, weathered into conspicuous monumental forms, one of which is shown on Pl. II, *B*. The dips of the beds are gentle, but change in inclination from place to place, indicating that moderate deformation of the nature of broad folding has occurred.

Rhyolite and rhyolitic tuff.—To the south, along a road that leads through an extensive and as yet unsurveyed region, indicated on the General Land Office map of Oregon as lying northwest of Cedar Mountains, the hills become bolder and more abrupt, assuming the characteristics of mountains. From 20 to 40 miles north of Harpers Flat the surface rocks over great areas are essentially horizontal, but deeply eroded. Broad rolling uplands devoid of trees but clothed with sagebrush and bunch grass are the dominant features of the landscapes. The table-lands are covered with basalt, but the presence on them of many flakes and shreds of black volcanic glass or obsidian indicates that sheets of superimposed rhyolitic tuff have been eroded away. Although basalt is the prevailing rock on the surfaces of the broad, plateau-like uplands, as well as in the precipitous walls of the canyons, sheets of rhyolite are also present, and



A. CONCENTRIC JOINTING IN RHYOLITIC LAVA, CROWLEY CREEK, MALHEUR COUNTY



B. EROSION COLUMNS OF VOLCANIC TUFF, COTTONWOOD CANYON, NEAR HARPERS FLAT, MALHEUR COUNTY.

to the south become at times the prevailing terranes in sight. Characteristically the basalt and rhyolite occur in essentially horizontal sheets, and give evidence of but slight disturbances.

The general features just mentioned pertain to the country traversed until Crowley Creek was reached, about 50 miles southwest of Harpers Flat, whence our route led west and northwest to South Fork of Malheur River, in the vicinity of Riverside. With our advance, however, rhyolite and rhyolitic tuff became more conspicuous than the outcrops of basalt, and at last formed the prevailing rock. Rhyolite is abundant in the region drained by Crowley Creek and thence west to South Fork of Malheur River. Some of the hills are composed of rhyolitic tuff and agglomerate in inclined layers, and are plainly the much eroded remnants of ancient volcanic tuff craters. From one such eminence, situated in the central part of T. 36, R. 26, and rising about 2,000 feet above the adjacent valleys, a widely extended view of the surrounding country was obtained, disclosing the leading characteristics of a region several hundred square miles in area. From the summit of this butte, which commands a view of about 100 miles in every direction, no rocks except rhyolite and rhyolitic tuff could be distinguished, even with the aid of a powerful field glass.

Without attempting to weary the reader with a presentation of notes, which, owing to the country being unsurveyed, can not be accurately located, I may say that the portion of Malheur County traversed bears evidence of having received a covering at different times of widely extended sheets of rhyolite and of rhyolitic tuff. The ruins of some of the volcanoes from which this material was extruded can still be distinguished. The lava, poured out in a molten condition, and the thick sheets of rhyolitic tuff are evidences that these volcanoes were of the explosive type and showered vast quantities of ejecta on the country in the same manner that Mount Pelee and La Soufrière, in the West Indies, recently added a layer of volcanic dust and lapilli to the surface of the islands on which they are located.

It is an instructive fact that volcanoes erupting refractory material, largely of the nature of rhyolite, had a wide distribution in central and eastern Oregon during Tertiary time. The contributions of this nature to the surface rank in extent and thickness with the vast basaltic overflows of the same region. As stated in a previous report, the evidence now in hand shows that several veritable inundations of basaltic lava occurred in eastern Oregon (as is shown, for example, by the exposures of rocks of that nature more than 5,000 feet thick in the east-facing escarpment of Steins Mountains) and were succeeded by great rhyolitic eruptions. Still later than the rhyolite came a renewal of basaltic eruptions which continued from time to time almost to the present day.

DRAINAGE AND WATER RESOURCES.

Throughout the portion of Malheur County traversed, and in fact over nearly all of central Oregon, there is abundant evidence of greater precipitation and more active erosion immediately preceding the present period of aridity and weak streams. The present streams, often the diminutive representatives of former rivers and creeks that excavated wide valleys, are now, in many instances, engaged in filling or aggrading their ancient channels. In many cases the present streams are ephemeral and flow only during the wet season, and many broad, flat-bottomed valleys of erosion are without surface drainage. Outstanding buttes, and mesas surrounded by mural escarpments, and sharp ridges, trenched on their slopes by deep excavations, etc., speak of climatic conditions different from those which now exist and make it evident that the leading feature in the climatic change that has taken place was a decrease in humidity.

The surface of the valley between Ontario and Vale and the continuation of the same broad depression for 6 or 8 miles upstream from Vale presents many interesting features in reference to the manner in which streams shape land surfaces and leave records of their work in terraces, flood plains, sloughs, etc. The flood plain of the Malheur, between Malheur Butte and Vale, is in general about 4 miles wide, and during exceptionally high-water stages is inundated. These expansions of the river occur in spring, when much floating ice is brought down from the upper reaches of the stream and left stranded on the flooded tracts. In some instances considerable quantities of gravel and sand, attached or frozen into the ice, are brought down, to be deposited irregularly in association with the fine silt that the expanded waters sift down on the land they temporarily cover. The stream in summer is greatly reduced in volume, and in recent years, owing to the demands made on it for purposes of irrigation, usually becomes dry in July and August, or has water only in the deeper depressions in its bed and in adjacent sloughs. It may be classed as an alluvial stream in this portion of its course; that is, one engaged in filling in its valley, or aggrading. It flows in many curves through the nearly flat land it has formed, and furnishes excellent illustrations of the meanders that sluggish rivers develop, and also characteristic examples of the cutting off of curves during periods of high water. The portions of the curves thus abandoned form sloughs and illustrate the character and mode of origin of oxbow lakes. The surface layer of the flood plain, as is usual in such formations, is largely composed of fine silt. The depth of this layer is in general about 10 to 12 feet, and beneath it is coarse gravel. The gravel was also laid down by the stream and is the lower member of the flood-plain deposits. Wells dug in the flood plain reach water on entering the gravel, finding there an abundant supply for household purposes, watering of stock, etc. As yet, however, none is pumped for use in irrigating.

In the northern half of Malheur County, the only portion here considered, the flat lands suitable for irrigation are located mainly along the border of Malheur River, below Grove. There are small areas of bottom land farther up the stream, as at Harpers Flat, and also an area of several square miles on the Owyhee near its mouth and adjacent to Snake River, which are of value for agriculture, and in fact are now, to a considerable extent, under irrigation. The valley of the Malheur, from near the site of the former post-office of Grove, about 6 miles south of Vale, north to Snake River, contains a large amount of rich agricultural land (about 100 square miles, by a rough estimate) well located for irrigation; but at present, owing to scarcity of water during the growing season, farmed to but a small extent. In a state of nature this extensive and beautiful valley was a meadow of luxuriant bunch grass and tall, grain-like rye grass; now, owing to overgrazing, it is essentially a desert.

The only surface water available for irrigating the lower portion of Malheur Valley is that flowing through the channel of Malheur River. Along that stream there are favorable sites for storage reservoirs, which could be made to retain all of the winter run-off. One such site, that at Harpers Flat, or Harper's ranch, has already been investigated by the United States Geological Survey.[a]

Owyhee River also furnishes desirable localities where storage reservoirs could be advantageously, and I think, economically, constructed, and its winter run-off conserved for use on the flat lands near its north end, adjacent to Snake River. The possibility of diverting a portion of the waters of Snake River onto these same lands has been suggested, but the enterprise is one of such magnitude that detailed surveys are necessary before even an approximate estimate of the benefits to be expected can be made.

From such facts as are known concerning the extent of the lands along the lower course of Malheur River and near where Owyhee River joins Snake River, which are favorably situated for irrigation, and also concerning the volumes of Malheur and Owyhee rivers, it is evident that when all of the available water, including the winter run-off, shall have been utilized, only a comparatively small portion of the land can be made productive. Another source of supply has been pointed out, namely, the Lewis artesian basin,[a] which includes much of the region under consideration, but the quantity of water that can be obtained from that reservoir and the area of land below the artesian head of the basin are as yet only approximately known. Seemingly, however, under the most favorable results to be expected from the use of artesian water for irrigation, only small areas, principally gardens and orchards, can be supplied.

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[a] Second Ann. Rept. Reclamation Service, U. S. Geol. Survey: H. Doc. 44, 2d sess. 58th Cong., 1904, p. 435.

The portion of Malheur County traversed to the south of Grove, with the exception of certain small areas immediately adjacent to Malheur River, is almost entirely destitute of water, and owing to its considerable elevation, rugged topography, and especially its deep dissection by streams, is, so far as can be judged, beyond the hope of reclamation by irrigation. The nature and structure of the rocks are not such as to suggest the presence of artesian basins. The value of the region evidently lies in its use for grazing, and even for this purpose the scarcity of water prevents stock from reaching extensive natural pastures which are still clothed with luxuriant bunch grass.

Previous journeys have shown that these remarks apply equally well to the greater portion of Malheur County farther south. There are a few notable exceptions to the barrenness of the land, especially along some of the small streams and where springs come to the surface, producing abundant crops of native grasses, but their combined areas are probably less than 1 per cent of the area of the uplands, on which there is no suggestion that irrigation can be practiced. The aridity of Malheur County throughout, and the scarcity of water, whether surface or artesian, are such as to show that the chief economic returns it can be expected to furnish are in the direction of stock raising. The practical lesson furnished by these considerations is that the utmost economy in the use of the limited water supply should be practiced and the most thoroughly scientific methods of agriculture and horticulture employed wherever practicable.

HARNEY COUNTY.

GEOLOGY AND TOPOGRAPHY.

The sheets of rhyolite and of rhyolitic tuff which form so conspicuous a feature in the geology of the west-central part of Malheur County continue west and are well exposed in the hills to the east of Harney Valley. In this region, however, the nearly horizontal position of the beds, noted farther east, becomes less conspicuous, and faults, accompanied by tilting of the rocks adjacent to them, influence the topography to a marked degree, especially in the region drained by the headwaters of Crane Creek. In the uplands on the east border of Harney Valley extensive areas are occupied by basaltic rocks, and in the canyon walls rim rocks of both rhyolitic tuff and basalt are present. Beneath the resistant layers forming the rim rocks occur beds of soft stratified material composed largely of white volcanic dust.

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[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

SOUTH FORK OF MALHEUR VALLEY.

South Fork of Malheur River, near Crane, is situated in a deep canyon-like valley, which furnishes a record of extensive erosion, and is a part of a widely extended series of valleys and canyons, which bear evidence of having been excavated by streams of larger volume than those now flowing through them.

In the valley of the South Fork, near its extreme southern prolongation, and in the valley of one of its small tributaries, there is a fresh basaltic lava flow, the first of recent date met during the reconnaissance. It terminates in a steep slope at its distal end and along its bordering escarpments, and for several miles up the course of the congealed current shows evidence of a sluggish flow, due largely to the blocks of the broken crust which became involved in the material beneath while it was yet plastic. The surface of the lava is black, vesicular, and exceedingly rough, and over large areas has the characteristics of an aa lava surface—that is, it is composed of the broken fragments of the first-formed crust, piled in confused heaps, and in many cases standing on edge or inclined at various angles. Occasional pressure ridges are also present, produced by the upward bending of the thick rigid crust, with its involved fragments of the first-formed and thinner crust; these are due to lateral pressure produced by the flow of the lava beneath, or to the shrinkage of the lower portion of the material as it cooled.

The lava stream occupies the bottom of the canyon-like valley in which is occurs for a distance of at least 10 miles, and is, on an average, about a mile wide. Where Crane Creek joins Camp Creek its breadth is nearly 2 miles. The blackness of the lava and the scarcity of evidence of disintegration or decay, as well as the absence of vegetation other than sagebrush and the plants usually associated with it, give an impression of recency, but the weak stream that flows down the valley has cut a channel from 50 to 75 feet deep near where it leaves the lava. The scarcity of soil and of vegetation is due to the aridity of the climate, and is not in itself an index of youthfulness in the soil beneath, while the considerable amount of work accomplished by the weak and now ephemeral stream is suggestive of centuries of slow erosion. The lava stream can not, therefore, be considered as young in years, although, with the exception of the Jordan and Diamond volcanoes and lava flows,[a] it is the latest considerable addition to the surface rocks that has been made in eastern Oregon.

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[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

The valley in which this lava stream lies is a direct continuation of a level-floored gap which extends from Camp Creek westward and opens out into Harney Valley. This gap, or canyon-like valley, was excavated by a stream flowing from the broad basin in which Malheur and Harney lakes are situated, and is consequently an old river channel. Its level floor is a continuation of the present surface of the adjacent portion of Harney Valley, and is due to the lava flow. A direct connection between the fresh lava in the upper portion of South Fork of Malheur River and the similar but less rugged sheet just described was not established by actually traversing the entire length of the lava-floored depression; as seen through a field glass from neighboring hills, however, the two portions seem to be parts of a single flow. Their source is not known, but the nearest recent volcanoes, so far as present explorations have shown, are the Diamond Craters, situated about 15 miles to the southwest, and it is probable that they came from there.

CRANE CREEK.

From Camp Creek the road followed passes up Crane Creek and through a well-defined but peculiar gap or pass leading west to Harney Valley. Crane Creek receives Coyote and Gorman creeks as tributaries from the north. These two creeks and the upper portion of Crane Creek, above the abrupt bend in its course where the road leading to Malheur Lake leaves it, flow south in nearly parallel valleys, due mainly to faulting, and enter a large valley with bold walls, which trends about east and west. This larger valley has several peculiar features which at once attract attention. In a general view it appears as a deep stream-cut valley, about one-half mile wide, leading directly through the hilly country it traverses, and affording a low-grade pass to Harney Valley. The impression is that it was formed by a river which escaped from Harney Valley, but, as already stated, there is a similar valley some 10 miles farther south—the old river bed mentioned above—which is lower, and has an almost perfectly flat floor at the same level as the adjacent portion of Harney Valley. One is puzzled to know how two valleys so similar in their geographical relations came into existence.

In traversing the Crane Creek Pass, as it may suggestively be termed, from east to west, one ascends Crane Creek, which has a well-defined gradient, until about 10 miles below its ultimate source, where a steep ascent of about 100 feet leads to a divide, or rather a crest that would be a divide if surface waters were present, separating the slopes on the east draining to Crane Creek from the slopes on the west draining to Malheur Lake. On the west the floor of the pass is approximately level. Throughout the two portions of the old valley the width is about one-half mile, and the bordering escarpments are bold and steep, and in general 200 or 300 feet high. The valley is clearly the result of stream erosion, and is a part of the record inscribed on the land, showing formerly greater precipitation than now. The divide which crosses the course of the valley from north to south is due to movements in the rocks subsequent to its excavation, and is of the nature of a fault, the west side of which has been upheaved in reference to its eastern side. Other illustrations of faulting and tilting are present in the same region, and are suggestive of the causes which produced changes in the direction of flow of the modern streams in respect to their former and larger representatives.

In ascending Crane Creek from its junction with South Fork of Malheur River and passing west into Harney Valley, one leaves a region where rhyolitic rocks are well displayed and enters an extensive area occupied by basalt, bordering Harney Valley on the east.

For several miles along the middle course of Crane Creek the rocks are basalt, spread out in sheets ranging from 40 to 60 feet in thickness, and associated with sheets of soft sedimentary material, largely volcanic dust. The series of resistant basaltic sheets and weak interbedded sedimentary material dips gently westward. Conspicuous for several miles on the south side of Crane Creek Canyon is a rim rock of rhyolite and rhyolitic tuff of irregular thickness, in general measuring 40 to 50 feet on its vertical escarpments. This sheet of rhyolitic material, like many other similar sheets in eastern Oregon, occurs above a series of basaltic rocks and in turn is overlain by other basaltic overflows. In places the edge of the sheet exhibits good examples of spheroidal jointing, as illustrated on Pl. II, *A*.

Although, as stated above, basaltic rocks become the prevailing terranes as Harney Valley is approached by way of the Crane Creek Pass, rhyolitic rocks impress their characteristic colors on the landscape in the neighboring hills to the north. The Crane Creek Hills, for example, on the north side of the valley are, as previously recorded,[a] composed mainly of rhyolite and rhyolitic tuff.

HARNEY VALLEY.

From commanding elevations on the east border of Harney Valley that great level-floored basin with its surrounding hills and mountains makes an impressive picture. The valley, as is well known, is the largest single expanse of practically level land in Oregon; although irregular in outline, its diameter in any direction is approximately 50 to 60 miles. Extending into the level-floored basin, however, at several localities on its border are cape-like projections from the surrounding highlands, and well within its sea-like expanse are a few isolated buttes. The most conspicuous of the salients on its borders occurs on its west side, where a flat-top table-land of basalt, with steep bordering slopes due to erosion, projects at least 10 miles toward the center. Near the north and east shores of Malheur Lake are three buttes, which are conspicuous on account of their isolation and the flatness of the country in all directions about them. The monotony of the topography of the basin is also broken by a low swell rising to the east of Malheur Slough, about 5 miles west of the entrance to Crane Creek Pass, which is composed of basalt and is surrounded on all sides by fine soft clay-like deposits.

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[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

Saddle Mountain.—Of the three buttes referred to, only one, Saddle Mountain Butte, was visited. This butte, situated at the north side of Malheur Lake, is about 300 feet high and from 1 to 1½ miles in diameter. It derives its name from its shape, as seen from either the east or the west, being composed of two ridges, running about east and west, with a depression between them. The rocks are scoriaceous basalt. There is considerable loose scoria on the surface, but no bombs were found and no evidence of a cinder or lapilli cone. Although the eminence is probably the remnant of a volcanic crater, it is so deeply eroded that no positive assurance of such an origin could be obtained. Its borders are steep on all sides except the east and bear evidence of long-continued erosion, and the entire hill may reasonably be considered as a remnant of a basaltic plateau surrounding an old crater. It is now densely clothed with sagebrush, beneath which there is abundance of bunch grass.

From the summit of the butte a fine view is furnished of the great plain from which it rises. To the southeast may be seen two other similar buttes, situated near the east border of Malheur Lake, which from their color seem also to be composed of basalt. To the east the deep, flat-bottomed notch in the rim of Harney Valley, through which the draining stream of the plain formerly flowed, is in plain sight, although about 15 miles distant; the continuation of the valley floor into the bottom of the old channel without a perceptible change in slope is a notable feature. Farther to the southeast, about 50 miles distant, rises the rugged crest of Steins Mountains, on which snow lingers throughout the summer.

Malheur Lake.—To the south of Saddle Mountain Butte, and so broad that its farther shore can not be discerned from the summit of that elevation, lies Malheur Lake, some account of which has been presented in a previous report.[a] The lake is shallow, not over 8 feet deep in the deepest part, as I have been informed by persons well acquainted with it. A mile from its shore at almost any point the water is only a few inches deep. Its water is always yellowish with material in suspension, a common feature of alkaline lakes. It is in fact a so-called "playa lake;" that, is a lake which on evaporating to dryness leaves a mud plain or playa. Although Malheur Lake has never been known to disappear, it experiences conspicuous variations in area and may be expected to evaporate to dryness if but slight climatic oscillations favoring less rainfall or more active evaporation should occur. The open water of the lake is bordered by rank growths of dark-green rushes, which also form many island-like areas here and there on its surface, rising in general from a foot or two of water. During periods of high water the lake expands and reaches within a few hundred feet of the south base of Saddle Mountain Butte. East and west of the butte it frequently expands so as to carry its margin about 4 miles beyond its low-water limit. These fluctuations have not been observed long enough to determine what their maximum may be, and it would not be surprising if portions of the plain now inhabited, as, for example, the site of the village of Lawen, should be sometimes inundated. The portion of the lake bed now left dry each summer is in places brightly colored with the reddish and yellowish coral-like plant known as *Salicornia*, and is overgrown with salt grass, which is harvested each year.

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[a] Russell, I. C., Notes on the geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.

Hot spring.—About 4 miles northeast of Saddle Mountain Butte is a spring which, as observed by H. C. Dewey, forms an irregular pool from 75 to 120 feet in diameter and 20 to 30 feet deep. The water is clear, without odor, and near the margin of the pool has a temperature of 122° F. The discharge, which is about 430 cubic inches per second, is now utilized for watering stock. This spring rises at a locality on the surface of the broad valley, at least 4 miles from the nearest upland, and is a true fissure spring, having a deep source, shown by its temperature to be probably not less than 3,500 feet below the surface. Like other hot springs in the same valley, some account of which has been published,[a] it indicates the presence of artesian conditions.

Wells.—At the village of Lawen, situated about 6 miles west of Saddle Mountain Butte and about 3 miles north of the summer margin of Malheur Lake, eight wells have been drilled, and within a radius of 2 miles of the village six other wells have been put down. These wells range in depth from 18 to 40 feet, the differences being due principally to the inequalities of the surface, as they all obtain their water from about the same horizon. They pass through fine yellowish silt, and reveal the nature of the surface layer that covers large portions and, as nearly as can now be judged, practically the entire area, of Harney Valley. The material is fine throughout, with but slight indications of stratification, and contains no beds of gravel or other coarse deposits. It agrees in physical character with the silts the rivers of the region deposit during high-water stages. Similar material was observed on the banks of Silvies River, and also on the borders of Malheur Slough, as the channel is termed, through which Rattlesnake and other creeks on the north side of Harney Valley discharge to Malheur Lake during periods of high water. It is probable that the widely extended sheet of material forming the surface of Harney Valley is mainly a stream deposit, while the portion near the lake was laid down in still water. This is an instructive illustration of the fact that stream and lake deposits merge into each other and in many instances have no definite line of separation. On the surface of Harney Valley also there are wind-laid deposits of sand and dust, but for the most part they are inconspicuous.

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[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

The depth at which water is reached in the wells in and about Lawen shows the position of the water table, which is probably controlled by the surface level of Malheur Lake. The water is raised by means of windmills and is used for domestic purposes, watering stock, and the irrigation of small gardens. The supply seems to be inexhaustible. The temperature of the water in one well, 18 feet deep and 14 feet to water, is 50¼° F., which probably represents about the mean annual temperature of the locality.

In the southern part of Lawen, on land belonging to Mr. G. L. Sitz, a well 5 inches in diameter was drilled in the year 1900 to a depth of 432 feet with the hope of obtaining artesian water. The water table was reached at 10 feet and artesian water at about 200 feet; below that depth, as thought by the driller, no additional water was obtained. The well discharges continuously through a 3-inch pipe. The section passed through, as reported by Mr. Sitz from memory, is as follows:

Section in well at Lawen.

	Feet.
Sand and clay	200
Lava, about	50
Gravel, cemented	4
Hard and soft layers, from 8 inches thick to 4 feet thick	100
"Hard blue granite" (basalt)	78
Total depth	432

This fragment of information concerning the geology of Harney Valley is in harmony with what has previously been learned in reference to that basin, and indicates that artesian water can be had if drill holes are put down. To adequately test the artesian conditions at Lawen, a well at least 1,000 feet deep should be drilled, but the possibilities in reference to water stored under pressure will not even then be exhausted, as water-bearing layers probably exist at still deeper horizons.

The depth of the surface layer, 200 feet, given in the above section, is of interest and indicates that the surface filling of the valley is not great. Beneath the silt, reported as "sand and clay" by Mr. Sitz, there probably occur sheets of basalt, rhyolite, and rhyolitic tuff, perhaps with lacustral or stream-deposited sediments such as clay, sand, and gravel between them. So far as the facts in hand furnish data on which to judge the structure of the rocks, the position in which they occur, and their nature, whether porous or impervious, all favor the hope, as previously reported, that flowing water can be obtained over a large part of the basin.

Soil.—The broad, level expanse of Harney Valley is traversed by roads connecting localities where water can be obtained, and but for the wire fences placed about the extensive tracts held for pasturage the level-floored valley could be crossed by wagon in practically all directions. A representative portion of the valley, situated between Lawen and Burns, shows that the surface has minor inequalities due to the abandoned channels of streams flowing from the surrounding uplands. The surface of the soft material forming the present floor of the basin is alluvium brought by streams from the uplands and deposited in broad, low-grade, alluvial fans. Over these deposits the streams have run in various channels or distributaries, and as they shifted their positions the abandoned channels remained as records of their former courses. Over the stream-shaped surface the winds have deposited some material in the form of sand and dust, but this covering is thin and in most localities inconspicuous. Even the transient visitor is impressed with the fact that the valley contains a vast quantity of good land which only needs water to make it fruitful. The climatic conditions, however, and especially the common occurrence of frost in summer, render it evident that in the future, as in the past, industrial development will consist principally in hay growing as a basis for stock raising and in dairying.

Rhyolitic tuff.—At Burns and especially along the border of Silvies River, to the west of the town, there are conspicuous outcrops of rhyolitic tuff. A widely extended sheet of this material underlies the surface over a great extent of the hilly and even mountainous country to the northwest, but its boundaries have not been traced. The region referred to is forest-covered and furnishes the watershed of Silvies River. An intimate relation between the character of the surface rock and the water supply is here shown, since the thick sheet of tuff referred to (as may be seen in the rim rocks bordering the narrow valley through which Silvies River flows) is porous and absorbs the rain water falling on its surface, allowing it to percolate slowly to the stream. In the valleys cut in the widely extended tuff sheets, hillside springs are common. The tuff is well exposed at Burns, and, as may there be seen, is a brown porous rock of low specific gravity, composed of angular fragments of scoriaceous rhyolite. The beds are easily quarried and the blocks obtained readily squared for building purposes by means of an ax. Although an inferior building stone, because of its porosity, which permits it to absorb water almost as readily as a sponge, and because also of its sombre color, it is nevertheless useful, especially in a region where the rainfall is small. A church at Burns has been built of it, and this and similar material will no doubt be extensively used in the towns of central Oregon in the future.

LITTLE SAGEHEN CREEK.

The stage road leading southwest from Burns follows the border of Harney Valley for about 6 miles and then turns west, crosses a low divide, and ascends Little Sagehen Valley. Through this runs Little Sagehen Creek, the diminutive representative of the former stream of considerable size that excavated the well-defined valley. It is dry in its upper part in summer, but in its lower part several warm springs come to the surface and supply natural irrigation for extensive meadows of native grasses.

The rocks forming the major portion of the hills southwest of Burns are composed of rhyolitic tuff, similar to the brown building stone at Burns, but a prominent butte, overlooking both Harney Valley and the narrow stream-cut valley of Little Sagehen Creek, is composed of reddish scoriaceous basalt, a remnant left by erosion of a formerly extensive sheet of the same material. Little Sagehen Creek has cut a steep-sided trench-like valley through the basalt, leaving a broad plateau on each side, that on the north extending east to within about 6 miles of Malheur Lake, where it terminates in a line of bold escarpments. The sheet of basalt also extends widely to the south of Little Sagehen Creek, forming a nearly level plateau which reaches nearly or quite to Little Silver and Harney lakes. Over the monotonous surfaces of these broad plateaus the bare black basalt with which they are covered is nearly everywhere exposed. Along each side of Little Sagehen Creek for a distance of about 25 miles, the broken edges of the lava sheet form bold palisades about 40 feet high, below which steep talus slopes conceal from view the soft stratified beds underlying the resistant lava that shields them and that, where unbroken, has preserved them from erosion.

From the basaltic butte referred to above good views were obtained of the mountainous country to the northwest of Burns, which confirmed previous observations in reference to the eastward dip of the rocks in that region and showed that they pass beneath the floor of Harney Valley, thus favoring the conclusion that artesian conditions are present beneath its broad arid surface.

The north wall of the canyon of Little Sagehen Creek for a distance of about 10 miles near its head is composed of irregular hills of rhyolitic tuff, the weathering of which has produced numerous isolated crags and monumental forms. On the south the canyon is bordered by a continuation of the palisade of basalt, marking the border of the extensive plateau, which extends far to the south. The basalt is here thin, in places being not over 15 or 20 feet thick. Beneath it are soft white sedimentary beds, consisting largely of volcanic dust, at least 250 or 300 feet thick. The basalt was spread out as a widely extended sheet after the rhyolitic tuff, which was showered on the land in vast quantities, had been consolidated and deeply eroded. After the inundation of basalt erosion continued, and the canyon of Little Sagehen Creek was excavated. From our general knowledge of the relations of the rhyolitic tuffs and basalts of central Oregon to sedimentary rocks containing fossils it may reasonably be inferred that the soft beds in question are of Tertiary age. The cutting of the canyon in the basalt is, it seems, an event of post-Tertiary time.

At the head of Little Sagehen Valley there is a low, irregular, flat-topped divide. The road leading westward ascends from the canyon by means of a steep grade and traverses a portion of the basaltic plateau referred to above. The junction of the basalt with the older rhyolitic tuff, which there forms irregular hills, can readily be traced 1 or 2 miles to the right of the road. The tuff has been deeply dissected by streams, and furnishes examples of old topography in striking contrast with the level surface of the adjacent plateau of basalt, with its few steep-sided gorges and canyons. The tuff of the uplands is well exposed, and in the walls of deeply cut but flaring valleys sections of beds from 50 to 150 feet thick are revealed. The rocks resemble gray granite in color and, like granite, weather into rounded hills with crags and isolated tower-like masses on their sides and in the walls of the bordering ravines.

SILVER CREEK.

Silver Creek has its source in a dissected plateau, which is an extension to the northeast of the hills just referred to. In summer its upper portion becomes dry and its sole supply is from great springs of cool, delicious water that well out at the base of a bold escarpment of yellowish rhyolitic tuff about 8 miles northwest of Riley. Below these springs is an alluvial plain about 10 miles long and averaging approximately 2 miles in width, through which Silver Creek meanders, bordered by rich agricultural lands. The water supply is meager, however, and only a small percentage of the land favorably located for irrigation is under cultivation. About 2 miles south of Riley the valley contracts and becomes a gorge with bluffs and rim rocks on its sides. Bold hills of basaltic rock rising near the creek on its south side have the form and appearance of much-eroded volcanic craters. About a mile south of these hills is the true border of the valley, there defined by a rim rock of basalt which trends southwestward and forms the southeast border of a valley or depression tributary to that through which Silver Creek flows. The line of cliffs is a conspicuous topographic feature and one of much geologic interest. To the south of Riley it is from 200 to 300 feet high, and from its crest the descent to the southeast is abrupt for about a quarter of a mile, when the surface of the broad basaltic plateau extending far to the south and east is reached. The sheet of basalt forming the plateau is evidently slightly upturned along the line of cliffs defining its northwest border, and is broken so as to form palisades. These conditions indicate the presence of a fault, as will be shown more clearly a few pages further on.

PROMINENT PEAKS.

From east to west across central Oregon there is a succession of prominent peaks which serve as landmarks to the traveler and furnish a series of convenient stations for studying the geography and geology of the region lying between Steins Mountains on the east and the Cascade Mountains on the west. These peaks, in their order from east to west, are: Iron Mountain, a sharp conical elevation about 5 miles south of Little Silver Lake; Placidia Butte, 18 miles northwest of Iron Mountain; Glass Buttes, 18 miles farther northwest; Hampton Butte, 12 miles northwest of the Glass Buttes, and the Pauline Mountains, about 30 miles farther west, from which the Cascade Range is in full view, although 50 miles distant. In the interval there are several isolated peaks, such as Pilot Butte, Lava Butte, Black Butte, etc.—steep-sided conical elevations with sharp summits, ranged across the country like signal stations—each of which at some time in its history has been aglow with volcanic fires. They are not all of the same age, and, although having a similar history, present many variations in the details of the events they record. Some of them, like Iron Mountain, the Glass Buttes, and Hampton Butte, are of ancient date, and were built by volcanic explosions which hurled fragments of congealed lava into the air during the earlier part of the Tertiary period of geologic history; others, like

Lava Butte, covered the region about them with streams of molten lava but a few centuries since.

Iron Mountain.—Iron Mountain, some account of which has been given in a previous report,[a] is a much-eroded volcanic cone built of acid lava resembling rhyolite. It commands a far-extended landscape, characteristic of the arid east-central portion of Oregon; from its sharp summit not an individual tree can be distinguished, although the shadow-like appearances on the mountains far to the north are known to indicate the presence of a valuable forest. About the base of the butte are widely extended basaltic lava flows, and near at hand broad, yellow mud plains margined by bands of white efflorescent salts. The waters of Little Silver Lake lap on shadeless shores, and serve to emphasize rather than relieve the desolation that forms the most prominent feature of the landscape in every direction. To the northwest, 18 miles distant, rises the sharp summit of Placidia Butte, the most prominent object in a seemingly boundless plain of somber sagebrush-covered basalt.

Placidia Butte.—The nearest habitation to Placidia Butte is at Riley, about 12 miles eastward, the road for the entire distance being without water, except such as is furnished by melting snow in winter and spring or by the stagnant contents of small water pockets in early summer. During our visit to the butte we crossed the Silver Creek Meadows to the base of the bold palisade or rim rock that borders them on the south. Choosing a notch in the almost continuous crest line of the palisade the top was easily reached. The crest of the palisade, instead of being the margin of a level plateau, as is so frequently the case where rim rocks occur, is really the edge of a tilted block, which stands in relief above the gently sloping plain that extends from its base 20 or more miles to the southeast. Along the crest of the ridge there are numerous elevations having about the same height, between which notches occur resembling the abandoned stream-cut channels termed "wind gaps." That they were really stream cut was not satisfactorily determined, but they at least suggest that the region was dissected by small streams tributary to a southeastward-flowing river before the ridge was uplifted.

The plain extending southeastward from the ridge slopes downward gently from its base, and is remarkable for its evenness and smoothness. No more than faint suggestions of stream-cut channels are visible on its vast monotonous surface. If such once existed, as is probable, they have been filled and obliterated by alluvium and wind-deposited débris. To the southeast Iron Mountain and Little Silver Lake are in plain view and seemingly only 8 or 10 miles away, instead of 18 or 20 miles, as they really are. To the southwest, 7 or 8 miles distant, rises the remarkably regular conical peak known as Placidia Butte, with a height above the adjacent plain of from 700 to 800 feet. On its eastern side, about a mile from its base, is a much lower elevation, composed of reddish, highly scoriaceous basalt, much eroded, which marks the site of a secondary or parasitic eruption. Possibly a stream of lava came to the surface at this locality, but erosion has so altered the topography that definite evidence of such an occurrence is not obtainable.

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[a] **Russell, I. C., Notes on geology of southwestern Idaho and southeastern Oregon: Bull. U. S. Geol. Survey No. 217, 1903.**

On ascending Placidia Butte we found it to be a volcanic cone built during explosive eruptions, which blew out angular fragments of scoriaceous basalt, but discovered no bombs to show that plastic lava was erupted. The sides of the cone are steep, and when seen in profile reveal long sweeping curves concave to the sky, typical of many similar cones composed of hard fragments of various sizes. It is doubtful if these curved slopes are a part of the original constructional surface of the cone, however, since much erosion has occurred, and erosion curves in the case of such piles of loose débris simulate constructional curves. On the southwest side of the cone there is a line of rough crags of scoriaceous basalt; on the west there is a similar line; and on the north there are suggestions of a third. These lines of crags radiate from the summit portion of the pile and mark the location of cracks in its sides, which were injected with molten lava so as to form dikes.

All these features are normal, or at least common, in the case of scoria and lapilla craters. An exceptional occurrence, however, is furnished by the massive angular crags of reddish-brown rock which form the summit of the cone and enable erosion to give it a sharp terminus. This summit mass, or capstone, is a volcanic agglomerate, but unlike most similar rocks, is lacking in fine material, such as volcanic dust and lapilli, to serve as a mortar for the larger masses. It is composed of sharply angular fragments of scoriaceous basalt, adhering firmly one to another and ranging in size from 1 or 2 up to 8 or 10 inches in diameter. In places there are angular holes and irregular cavities between the adjacent blocks. The explanation is that this agglomerate is composed of fragments blown out of the deeper portion of the conduit in a solid condition, and accumulated in the crater at the top of the volcanic pile as the volcanic energy decreased. The finer fragments, being carried higher, fell outside the crater or were removed by the wind. The larger fragments were hot and adhered to one another, the accumulation being also to some extent consolidated by the pressure of its own weight. The mass of material thus produced was similar to the "cone of eruption" observed in the case of many active or recently extinct volcanoes, and at first was encircled by a lapilli crater.

Stated in another way, the agglomerate is the higher portion of the plug or neck which hardened in the volcano's conduit as its energy decreased. At no great depth below the portion now exposed compact lava may be expected to be present. Erosion has removed the crater which once surrounded the summit of the plug and a portion of the compact agglomerate which accumulated within it. The central mass is resistant to all forms of mechanical erosion, and, owing to the dryness of the climate, has not been exposed to active chemical erosion. Although the plug is probably about 200 feet in diameter at a short distance beneath the exposed top, its summit has weathered to a rough but moderately sharp apex.

From the summit of Placidia Butte an unobstructed view in all directions is obtained. Perhaps the most characteristic features of the desolate landscape are the vast expanse of the apparently smooth plain of basalt, extending, with its covering of sagebrush, far to the east and southeast, and the hills to the south in the vicinity of Abert Lake, which, judging from their forms and the little that is known concerning them, are much eroded uplifts of rhyolitic lava and tuff of the same lithologic character.

Glass Buttes.—To the west, 18 miles distant, rise the Glass Buttes, consisting of two prominent rounded domes and several lesser hills, which, as known from a previous visit, are remnants of ancient rhyolitic or andesitic volcanoes, now deeply dissected by erosion. They form not only a most prominent object in the vast desert landscape, but add a touch of color to the prevailing gray of the surrounding sagebrush-covered plain by the tawny yellow of the ripened bunch grass and the dark shades of the trees that grow on the northern sides of their prominent ridges. The highest point on these desert mountains, which take their name from the obsidian or volcanic glass scattered over their surfaces, is approximately 2,000 feet above the plain surrounding their widely extended base.

Hampton Butte.—Hampton Butte, which is of similar geologic structure to the Glass Buttes, is situated a little to their right, and about 30 miles away from Placidia Butte, from which it may be seen. From Placidia Butte, in the blue, indefinite distance, may also be noted the snow-covered summits of the Cascade Mountains; these, however, are so dim, as seen through the ever-prevailing desert haze, that only Mount Jefferson can be definitely located.

HILLS AND RIDGES.

Continuing northward past a water pocket lying about a mile north of Placidia Butte, we again crossed the ridge that overlooks Silver Creek Valley and its southwest tributary, and found it to be composed in part of white rhyolitic rock of older date than are the vast sheets of basalt associated with it. Passing through a depression in the rhyolite hills, we gained a platform of basalt which encircles them on the northwest side. This platform, which is about half a mile wide, terminates on the northwest in a precipitous escarpment ranging in height from 200 to 300 feet, in which the edges of several sheets of basalt are well exposed. This escarpment is a direct continuation of the similar precipice climbed in the morning, and judging from its topography is the upraised side of a fault. The trend of the line of cliffs is northeast and southwest, but near its southern end it curves westward. The valley at its base on the west is not floored with alluvium, but has an irregular bottom composed of basalt, which rises in a continuous slope toward the northwest and culminates in the crest of a ridge which presents a steep slope to the west. A detailed study of this interesting region would no doubt yield much valuable data in reference to the influence of movements in the rocks on topographic forms.

To the north of Riley and bordering the meadows and adjacent sagebrush-covered terrace-like uplands on the northeast rise a group of bold rounded hills, which attain a height of between 1,500 and 2,000 feet above the meadows at their base. These hills are composed of compact, apparently basaltic rock, and are thought to be of probably Tertiary age. The hills, although presenting rounded summits when seen from the south, were found on near inspection to consist of a series of nearly east and west ridges, with steep escarpments facing north. This peculiar topography suggests faulting. The hills are thickly strewn with weathered blocks of rock of the same character as those exposed in the cliffs, but scoria, lapilli bombs, etc., are absent. As there are no trails, the thickly strewn blocks covering the surface make traveling difficult. Rich, brown residual soil occurs between the loose stones, and luxuriant bunch grass and an open forest of junipers and pines clothe the surface. These hills extend at least 8 miles northward, and present throughout the same topographic characteristics. Their northern extension is densely forested.

At the head of the Silver Creek Meadows there is a great spring of clear, cool, delicious water, at which a military fort called Camp Curry was formerly located. The spring, with others that occur along its course farther north, is an important source of supply for Silver Creek, which here emerges from a narrow canyon cut in a bed of rhyolitic tuff at least 100 feet thick, the rock being of the same nature as the tuff at Burns, and presumably a continuation of the same great sheet.

At the spring the stage road from Burns to Prineville makes a sharp turn to the west and ascends the precipitous border of a plateau. The rock removed in grading reveals excellent illustrations of the angular fragments of which the tuff is composed. Highly porous, it has been leached by percolating water and changed from the brown color that unweathered portions usually present to bright pink and even white. Resting on the tuff is a sheet of black basalt about 20 feet thick, which, by protecting the weaker rock beneath, has led to the preservation of a nearly flat table-land many square miles in area. The road traverses this plateau for about 4 miles, crossing on the way the desiccated bed of an ephemeral lake, surrounded on all sides by a low rim of basalt. In summer the bed of this lake is a smooth playa, but in winter it is flooded and the traveler has to skirt its northern border.

FORESTED PLATEAU.

To the west of the generally smooth basaltic plateau the road enters an extensive plateau region that has been somewhat deeply dissected by streams. The surface rock is rhyolitic tuff of the same character as that of the sheet so well exposed along Silver Creek to the north of the site of Camp Curry. A remarkable and pleasing change is here experienced by the west-bound traveler, who passes from an area thousands of square miles in extent over which not a tree is to be seen to a region covered with an open but luxuriant forest. For 10 or more miles the road, which is smooth and hard, winds through the forest, now descending steep valley sides, traversing beautiful shadowy vales, and again ascending to the level of the general plateau surface, from which exquisite pictures of the primeval forest are beheld on every hand. The forest is composed mainly of yellow pine, as yet untouched by the woodman, and gives promise of great commercial value in the future when means for transportation shall have been provided. Beneath the tall, straight pines grow thickets of mountain mahogany resembling groves of olive trees, which here, as in many other localities on the uplands of Oregon, add picturesqueness to the rocks and crags among which they make their homes. The forest, so welcome after weeks spent in the glare of the sun on gray deserts, extends far to the north, and probably continuously to the Blue Mountains of eastern Washington. In part it is included in a national forest reserve, and if properly cared for and the mature trees harvested, leaving the younger ones time to grow, will be valuable for ages to come.

On the south this great forest terminates abruptly, and from beneath the shade of the great trees on its margin one can look down on the bare hills of the desert land which it borders. Yet the only conspicuous difference between the forested plateau and the bare hills to the south is the nature of the underlying rocks, the plateau being composed of rhyolitic tuff, while the hills have been carved mainly from sheets of basalt. Beneath the portion of the forest traversed the porous surface rocks drink in all the water that comes to them and permit it to slowly percolate away and feed the springs and the streams in the countless erosion channels. The general elevation of the forested country, about 5,000 feet, is, however, greater than that of the vast treeless region bordering it on the south, thus favoring cooler climatic conditions in summer and retarding evaporation, and the precipitation, especially the snowfall in winter, is probably greater on the broad upland than on the desert valleys with their isolated hills, although of this there is no positive record. More study is required to show which is the determining cause leading to such a conspicuous change in the flora. In fact the several conditions favorable and unfavorable to tree growth seem to be delicately balanced, and the special factor in control is probably not the same throughout either the forested or the unforested region.

At Buck Creek, which flows south from the forested plateau, the road descends to the extensive sage-covered plain in which Crooked River has its source and enters Crook County.

WATER RESOURCES.

The rainfall throughout Harney County is too small to permit agriculture without irrigation. Owing to the considerable general elevation—the lowest altitude being the surface of Malheur Lake, which is about 4,150 feet above the sea—and the clearness and dryness of the air, which permit active radiation, frosts are of common occurrence during every month of the year, and only forage plants can be expected to yield adequate returns to husbandry. The uplands and valleys alike were clothed with bunch grass while in a state of nature, and wherever the soil was naturally moist and not too alkaline the coarse rye grasses formed luxuriant meadows. These several conditions indicate that the chief farming industries must be stock raising and dairy farming. The problem that meets the hydraulic engineer is how to utilize the available water supply so as to best serve these demands.

SURFACE WATER.

Rivers and streams.—The surface-water supply, although well known to the residents of the country, has only just begun to receive critical study. About all has already been done that can be accomplished by individuals and small communities in the way of diverting and utilizing the summer flow of the streams, but the main resource lies in the direction of storing the winter run-off in upland valleys and conducting it through canals to the most favorable portions of the lower valleys. There are but two streams that offer favorable conditions for such enterprises on a large scale, namely, Silvies River and Donner and Blitzen River. Of these the former is by far the more favorable, and detailed surveys are in progress by the United States Geological Survey[a] for the purpose of determining accurately what can be accomplished by means of it. The possibilities of Donner and Blitzen River have not as yet been considered by hydraulic engineers, but they demand careful study, such general knowledge as is available concerning the valley through which it flows certainly favoring the hope that advantageous sites for storage reservoirs occur along its course.

Water pockets.—About a mile north of Placidia Butte is a water pocket 500 or 600 feet in diameter, capable of holding 4 or 5 feet of water. This and several other similar depressions in the same region are of interest not only on account of their value as watering places for stock, but on account of their origin. Seemingly they are depressions due to wind erosion, but this explanation is not entirely satisfactory, since a similar basin on the forested plateau to the north of the Silver Creek Meadows has a rim of basalt all about it. These depressions are natural reservoirs in which water collects during the winter and spring months, but as they are filled to a depth of several feet with soft, fine silt their value as watering places for stock is much impaired. By reexcavating them a supply of water sufficient for a large number of cattle might be easily and cheaply procured.

HARNEY VALLEY.

The great plain forming Harney Valley and its several side extensions offers an abundance of irrigable land suitable for forage crops, far more in fact than under the most sanguine hopes can ever be reclaimed through the use of the water flowing from its bordering uplands. There is an urgent demand for more water than the run-off can supply, and to secure it the only resource is to obtain water by means of wells.

Wells.—Ordinary dug wells with a depth of less than 100 feet and usually less than 25 feet have proved successful in many portions of Harney Valley, particularly in and about Lawen, which is situated near the level of the lowest point in the basin. But while these wells are of value for household purposes and for watering stock, little use can seemingly be made of their water for irrigation. The hope for water for irrigation purposes, in addition to that furnished by surface streams, centers on a subsurface or artesian supply.

As explained in a previous report,[b] Harney Valley is located in an extensive depression, which for several reasons is considered to be an artesian basin that may be expected to yield a valuable water supply. The favorable opinion expressed in the report referred to in reference to obtaining artesian water was strengthened by the observations made during the reconnaissance which forms the basis of the present report, and the advisability of putting down a test well with all the care that can be exercised is again urged. A favorable locality for such a test, which should be carried as deep as practicable, is at or in the vicinity of Lawen.

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[a] Second Ann. Rept. Reclamation Service, U. S. Geol. Survey, H. Doc. 44, 2d sess. 58th Cong., 1904, pp. 435–436.

[b] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

Water storage.—In addition to Silvies River and Donner and Blitzen River, the possibilities for storing water on Rattlesnake Creek above the village of Harney, and also the advisability of constructing small reservoirs on Silver Creek above Riley, need to be investigated; but even at the present time it is evident that, owing to the limited water supply, the best returns to be hoped for from such undertakings are not great.

In the extensive area of hilly and even mountainous country embraced in the southwestern portion of Harney County the rainfall is small—probably less than 10 inches—and the land favorable for irrigation is restricted in area and widely scattered. The conditions do not seem to favor the storage and utilization of the surface water, and there is no suggestion of the existence of an artesian supply. This extensive region is favorable for grazing, however, bunch grass being abundant, and something can certainly be done in the direction of developing springs[a] and of deepening natural water pockets so as to obtain local supplies for maintaining stock during the summer months.

CROOK COUNTY.

CROOKED RIVER.

On emerging from the forest that occupies such an extensive area in the southwest part of Harney County we descended Buck Creek to the extensive valley at the east base of Hampton Butte, in which Crooked River has its source. The canyon of Buck Creek, which was traversed for about 6 miles, furnished a suggestion as to the character of the geology of the series of hills, or deeply dissected plateau, through which it flows. The canyon is from 500 to 600 feet deep, and has a conspicuous rim rock of basalt on each side, beneath which there are at least 700 feet of soft, mostly fine, sedimentary deposits, composed in part of volcanic dust. Along the canyon there is in places a narrow flood plain, which gives room for several small hay ranches. Where the creek emerges from the canyon and enters the broad valley or sagebrush plain to the south its water soon disappears, and even its former channel is almost lost in the wind-deposited sands.

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[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey, 1901.

GILCHRIST VALLEY.

The valley at the head of Crooked River, in which Buck Creek sinks, is about 20 miles long from north to south and, in general, 10 or 12 miles wide. On the southwest its border is low and indefinite, and in a general view it seems to merge with the Great Sandy Desert, which extends for at least 60 miles in a southeast and northwest direction across the southeast portion of Crook County and far into Lake County. This valley has no specific name, and for the sake of convenience, as well as a fitting acknowledgement of the enterprise and industry of its first settler, Mr. C. A. Gilchrist, whose hospitable home is still there, I propose to term it Gilchrist Valley. The valley contains, by estimate, fully 200 square miles of rich land, the greater part of it well situated for irrigation. Unfortunately, there are no surface streams rising in the bordering uplands that can be looked to for water enough to supply a single square mile. In a state of nature not only the valley, but the surrounding hills and buttes on all sides, were clothed with bunch grass, but now, owing to overgrazing, all the land not inclosed with fences within a distance of about 6 miles from any one of the few summer watering places is practically a desert.

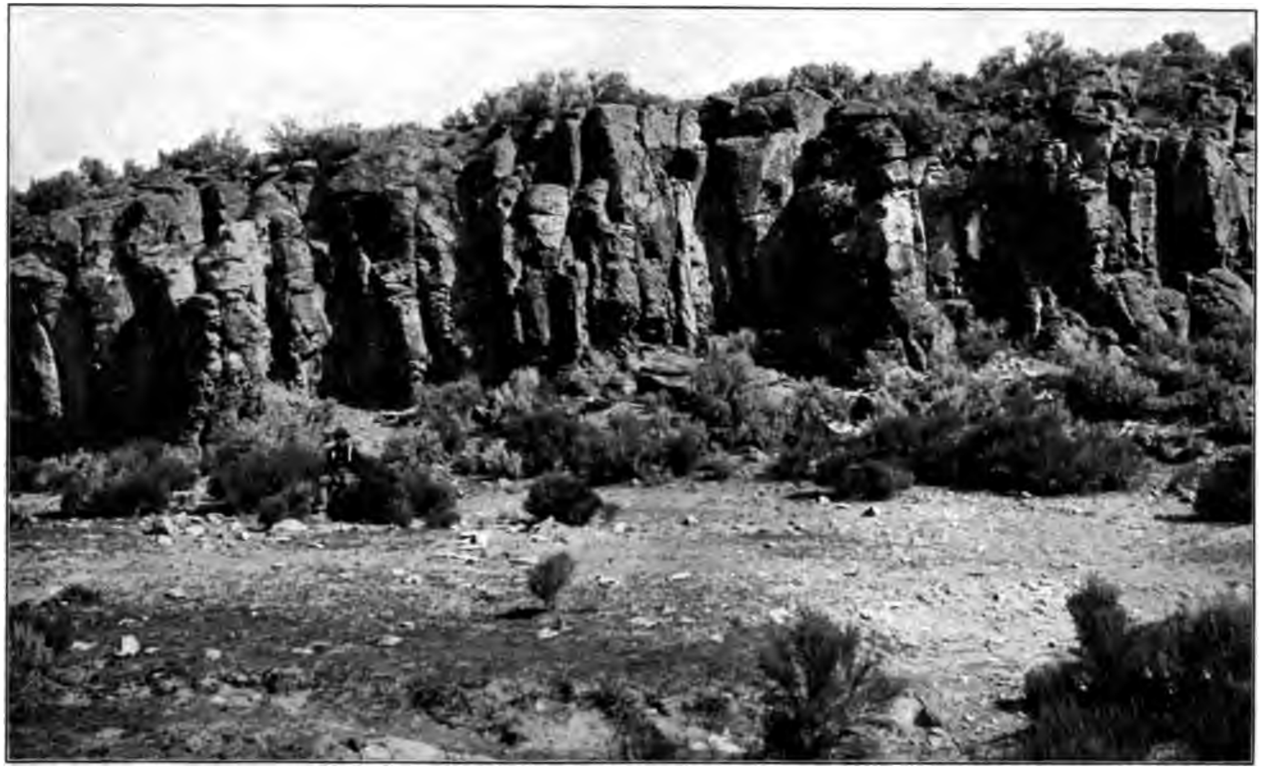
On the south border of Gilchrist Valley rise the Glass Buttes, to which reference has already been made, with bold, rounded summits and long, sweeping slopes, which make them particularly attractive, but they are desert mountains, rising from a featureless and excessively arid valley. The upland area on the north side of the buttes, which slopes to Gilchrist Valley, is extensive, but has no life-giving streams. On the west of the valley, rising boldly from its margin, stands Hampton Butte, a mountain mass similar to the Glass Buttes, and also waterless, so far as streams tributary to the adjacent valleys in summer are concerned. Uplands border the valley on the east, but are more remote and of less height than those on the west.

Warm springs.—Crooked River, which has its source in a group of warm springs at the north end of Gilchrist Valley, flows northward through an irregular, and, in part, "box," canyon, with a conspicuous rim rock of light-colored rhyolitic tuff on each side. Other springs swell its volume in the first few miles of its course. The land about the springs in the north end of the valley has been inclosed with fences, and the water that rises to the surface used for irrigation. Small storage reservoirs have been constructed, with favorable results. The land, although alkaline, by careful irrigation has been made to yield favorable crops of hay.

The warm springs in Gilchrist Valley are not only of interest on account of the use that is now being made of their waters, but because they supplement other evidence pointing to the probability that artesian water can be had over a large portion of the basin in which they are located. The springs range in temperature from 60° to 87° F. and are scattered for about 2 miles along a narrow north-and-south belt. They are all small, but it was not practicable to make accurate measurements of their discharges at the time of my visit, owing to the flooding of a part of the area where they rise by the storage reservoirs that have been constructed. Where the waters of the springs are combined at the outlet of the valley, they make a creek of warm water, the volume of which, by a rough estimate, is between 20 and 25 cubic feet per second. The temperature of the water, as it rises in the copious springs, indicates that it comes from a considerable depth. The rate of increase in temperature with depth is not the same at all points on the earth's surface, but where recent volcanic heat is not present is, in general, 1° F. for each 50 to 60 feet in depth below the stratum of no seasonal variation, which in Oregon may be taken at about 50 feet below the surface. The stratum of no seasonal variation has a temperature equivalent to the mean annual temperature at the surface, which in central Oregon is about 49° F. Assuming that the rate of increase in temperature with depth is 1° for each 60 feet, we find that the depth from which the spring in Gilchrist Valley are supplied is at least 2,200 feet. Perhaps a safer estimate, allowing for loss of heat as the water rises, would be 2,500 feet. At about that depth there is a supply of water at least sufficient to maintain the springs, which appear at the surface continuously throughout the year. As the springs rise through openings, in part at least, in soft material, there must be lateral seepage, and probably much loss in other ways. These springs may be justly termed artesian springs, as they flow by reason of the pressure of water at higher levels, and render it evident that if wells should be drilled to the requisite depth near them and properly cased a more abundant outflow might reasonably be expected.

Artesian wells.—While the presence of warm springs in Gilchrist Valley alone would furnish a strong argument in favor of drilling wells in their vicinity with the hope of obtaining artesian water, other facts also sustain the conclusion that they are situated in an artesian basin.

On all sides of Gilchrist Valley, except the northeast, the rocks dip toward it in such a way as to be readily seen. On the northeast the country rises for a long distance, until the forest-covered plateau drained in part by Silver Creek is reached, and the rocks become so nearly horizontal that the determination of their dip is difficult. On the north the layers of basalt and volcanic tuff are conspicuously flat, but, as revealed by the rim rocks on the sides of Crooked River



COLUMNAR RHYOLITIC TUFF AT NORTH END OF GILCHRIST VALLEY, NEAR HAMPTON BUTTE, CROOK COUNTY.

Canyon, are gently inclined toward the south for a distance of at least 10 miles. The hasty examination I was able to make favors the conclusion that Gilchrist Valley is situated in a structural basin. The rocks passing under the valley are in many instances porous, as may be seen in the eastern slope of Hampton Butte, along Crooked River, etc.; that is, they are of such a nature that they permit water to percolate through them. The presence of impervious layers, or rocks of such a close texture that, if resting on a pervious bed, they would prevent water from escaping upward from it, is less easy to demonstrate, and, in fact, no good evidence was obtained that such beds are present.

While it is not just to claim from the observations thus far made that Gilchrist Valley is in reality situated in an artesian basin, the facts presented above, and the impression gained while traversing the region and searching for adverse as well as favorable evidence as to a possible artesian water supply, certainly favor the opinion that a true artesian basin of considerable size is present.

The source of supply of the water rising in the springs referred to is most probably in the plateau region to the northeast, and, as the volume of the springs and the extent of the supposed gathering ground indicate, will probably be found ample to supply a number of artesian wells.

The object of my examination was mainly to determine if the conditions present warrant the expense of putting down test wells for the purpose of demonstrating the presence or absence of water under pressure. To this question, so far as Gilchrist Valley is concerned, an affirmative answer is abundantly justified. The test well may be located anywhere in the basin where flat land occurs, but would serve its purpose best if put down on the north and south axis of the valley, anywhere from 1 to 3 miles south of the Gilchrist brothers' ranch, on which the most copious springs come to the surface.

If a test well is put down, a careful record of the nature, thickness, etc., of the rocks passed through should be kept, the well properly cased, and the pressure of the water in every water-bearing layer met accurately measured. Suggestions in these and other directions, together with a list of reports, papers, etc., relating both to the theory of artesian water supply and the art of well drilling, have been presented in a previous report.[a]

PRICE VALLEY.

From the foot of Gilchrist Valley our route led westward to the now abandoned post-office of Price, situated on Camp Creek, at the south base of Mutton Mountain.

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[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.

At the outlet of Gilchrist Valley a bed of conspicuously columnar rhyolitic tuff, about 20 feet thick, which dips west at an angle of about 8°, is well exposed. (Pl. III.) The direction of the inclination of this and of other similar blocks in the vicinity is not the same, and in many instances is to be ascribed to landslides rather than movements having a more general cause. The prevalence of sheets of compact tuff and of basalt, resting on soft sedimentary beds or on sheets of fine, incoherent volcanic dust and lapilli, affords favorable conditions for the occurrence of landslides throughout an extensive region drained by Crooked River in the upper portion of its course and by Camp Creek, its principal tributary from the west. Along the canyon walls of these streams numerous illustrations of landslide topography are conspicuous.

The uplands between Gilchrist and Price valleys bear evidence of long-continued weathering, and stand in relief above the adjacent valleys because of the resistance offered to erosion by the widely extended sheet of rhyolitic tuff of which mention has already been made.

Camp Creek has excavated in soft sedimentary beds a valley in general 400 or 500 feet deep and about 2 miles wide. From its head to a narrow outlet, through which the stream escapes through a canyon to join Crooked River, is a distance of about 8 miles. In this basin, which it is convenient to term Price Valley, there are abundant outcrops of fine gravel and light-greenish shales, which in several localities have been weathered into typical badland topographic forms, as illustrated by Pl. IV. Much of the south side of the valley is crowned by a conspicuous rim rock of rhyolitic tuff, while the north side is more irregular and rises precipitously to form Mutton Mountain, the rocks of which are basalt. Basalt also forms a conspicuous remnant left by erosion on the south side of the valley.

John Day formation.—The soft fresh-water sedimentary beds so well exposed in Price Valley, particularly near its head, have become known to geologists on account of the large number of well-preserved fossil bones discovered in them, and have been shown to be a part of the John Day system. Judging from their close lithological similarity to the John Day beds at typical localities adjacent to the river after which they are named, descriptions of which have been published by John C. Merriam,[a] the lower and middle members of that series are represented, but I am in doubt as to the presence of the upper member. However, previous observers refer the beds in question to the middle and upper John Day.

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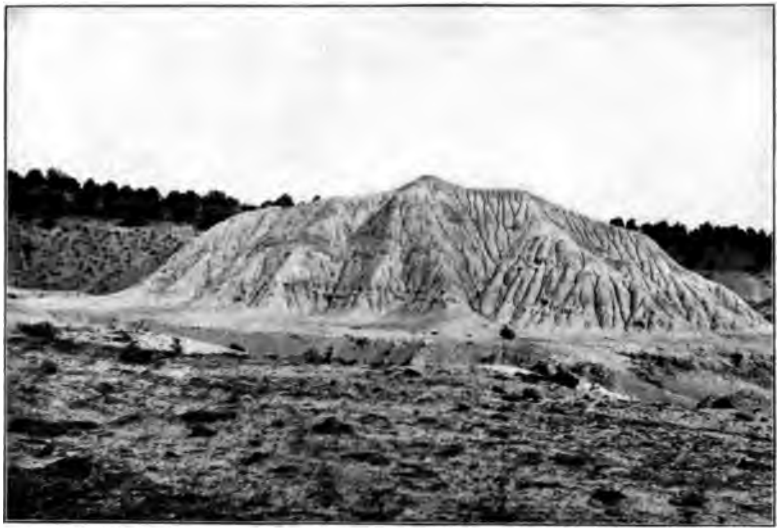
[a] A contribution to the geology of the John Day basin: Bull. Dept. Geology University of California, vol. 2, Berkeley, Cal., 1901, pp. 269–316. In this paper summaries of previous writings pertaining to the John Day formation are presented. A description of the fossil flora of the John Day formation, and a discussion of its geologic age, are presented by F. H. Knowlton in Bull. U. S. Geol. Survey No. 204, 1902.



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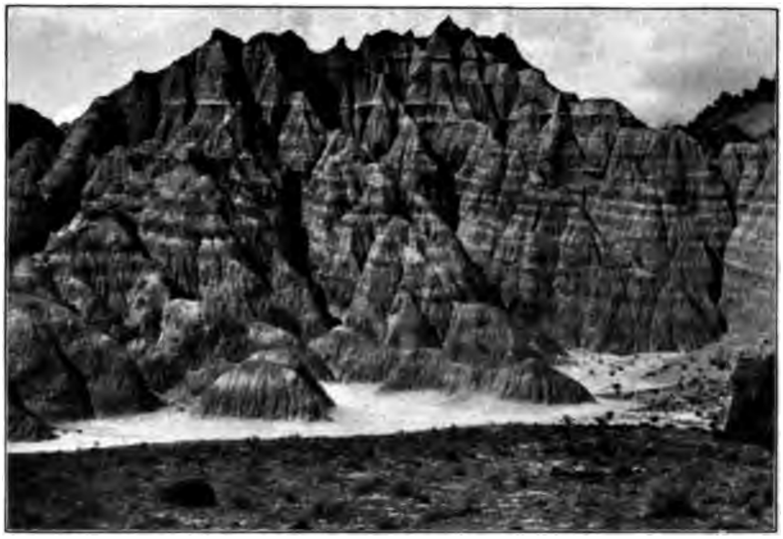

B

ERODED JOHN DAY BEDS, NEAR LOGAN BUTTE, CROOK COUNTY.

The lowest exposures in Price Valley consist of soft, highly colored shales, among which dark-red layers are conspicuous. Associated with these are similar beds, ranging in color from buff to white, and composed, to some extent at least, of volcanic tuffs. These beds, on weathering, produce rounded hills, in the sides of which the variously colored layers make concentric bands. These beds at least may be provisionally referred to the lower John Day.

Resting on the vari-colored beds just described are evenly stratified, bluish green shales having a dip of about 15° to the northeast, which are well exposed and form the most conspicuous outcrops of the valley. Their thickness was not measured, but is evidently considerable, probably amounting to 3,000 or more feet. Near Price the conspicuous bluffs of these bluish green shales have been penetrated by prospecting tunnels, in which the fresh rock has been revealed.

The best exposures of the bluish green shales, here referred to the middle John Day on account of their similarity to the rocks of that formation as described by Merriam, are seen between Indian Creek and West Camp Creek, where fine examples of badland topography occur. At this locality, rising from a most instructive group of deeply sculptured and artistically beautiful hills and ridges, is a prominent landmark known as Logan Butte, which is capped by a remnant of a resistant layer of rhyolitic tuff. The main portion of the butte and of all its flanking ridges, as well as of the associated but lesser buttes, has been carved from these light-colored shales. In these beds numerous well-preserved bones of extinct mammals have been found, but only a few imperfect specimens were obtained during my visit. A view of Logan Butte as seen from the south and a nearer view of its capping layer of resistant rhyolitic tuff are presented on Pl. V, *A* and *B*. The most interesting feature of the section exposed is the presence beneath the capping layer of tuff of nearly horizontal beds of dark-brown and reddish shales, volcanic dust, and conglomerate, which rest unconformably on the eroded surface of the conspicuously inclined middle John Day beds. These features are shown in more detail in the following section of the upper portion of the butte:

Geologic section of Logan Butte, Crook County, Oreg.

	Feet.
1. Compact, massive, homogeneous, light-brown tuff, with many angular fragments; no stratification lines; strongly jointed vertically; rests evenly and conformably on the bed below	50
2. Dark-red or brown sandstone passing below into yellowish brown stratified sandstone, in part tuff	35
3. Fine white volcanic dust or tuff	2
4. Brown sandstone, soft but weathering, with steep escarpments	8
5. Conglomerate composed of well-worn pebbles 6 to 8 inches in diameter, and varying in thickness	0 to 8
Unconformity.	
6. Blue-green and buff shales, dipping northeast 15° to 18°, evenly laminated, thickness exposed estimated at	800

Whether the stratified sedimentary beds above the unconformity noted in the section should be classed as upper John Day or as belonging to a higher formation remains to be determined.

Information in this connection has been supplied by Prof. John C. Merriam, of the University of California, who in a letter dated January 15, 1904, writes as follows:

> The exposures of John Day beds at Price, Crook County, Oreg., were visited by Mr. V. C. Osmont, of the University of California, in 1900, and from his notes I quote the following:
>
> "At Logan Butte itself, between 800 and 900 feet of the blue beds (middle John Day) are exposed. * * * On the northeast side of the butte they may be traced down the valley without a break for 1½ miles, and then are covered with alluvium for a mile, then as the ground rises, buff beds (upper John Day) for one-half mile occur. Wherever exposed the beds referred to have a dip of about 15° to the northeast."
>
> Judging from Mr. Osmont's description, and from the collections which he made at Logan Butte, I suppose both the upper and middle divisions of the system to be present. I do not remember whether I have mentioned any unconformity as existing between the middle and upper John Day. At one locality on the John Day River there seems to be an erosion interval represented between these two divisions.
>
> The formation which you mention as resting unconformably on the middle John Day at Logan Butte is described as follows in Mr. Osmont's notes:
>
> "The John Day is protected from erosion by a horizontal layer of very much more recent formation, resembling closely the hard, light, reddish columnar tuff which so universally covers the Loup Fork (Marshall formation). This tuff rests unconformably and horizontally on the middle or possibly the top of the blue beds (middle John Day), the tuff beds (upper John Day) and the uppermost part of the blue beds having been cut away at this point. This recent formation is made up of columns 30 to 40 feet through and 50 to 75 feet high. Beneath it are three or four distinct layers of red, blue, and yellow clay with white volcanic ash. The total thickness of this formation averages about 75 feet."
>
> At the time of Mr. Osmont's visit to Logan Butte I had not named and described the Rattlesnake formation, which you will find mentioned in my paper.[a] After his return, Mr. Osmont informed me that the formation at Logan Butte was almost exactly similar to the Rattlesnake formation of the John Day Valley.

Volcanic rocks.—The conspicuous capstone of Logan Butte is a remnant of a widely extended sheet, other and far larger portions of which form the surfaces of table-lands a few miles distant to the south and east. This sheet, as noted on the previous page, is well exposed in the rim rocks of Camp Creek and Crooked River canyons, and the soft beds beneath it are probably portions of the widely extended John Day formation.

At several localities on the borders of these canyons the layer of tuff presents two well-marked divisions, but there is no distinct plane of separation between them. The upper portion of the bed, which

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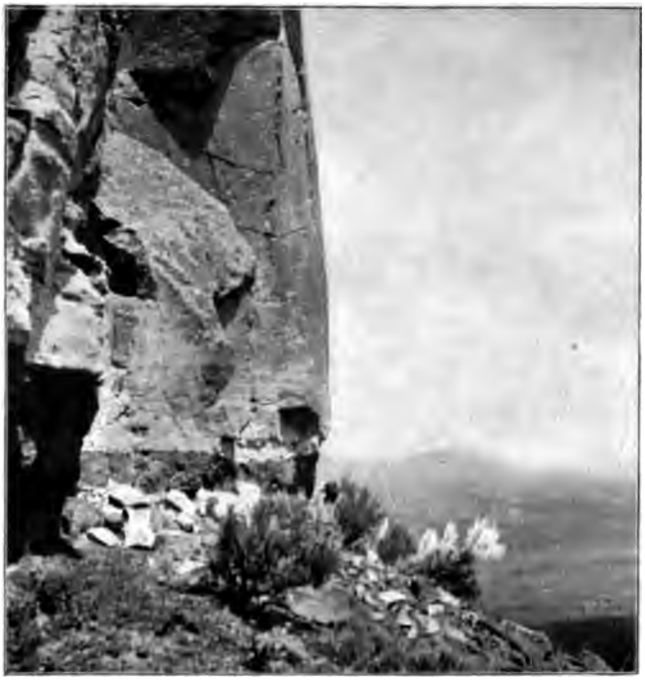
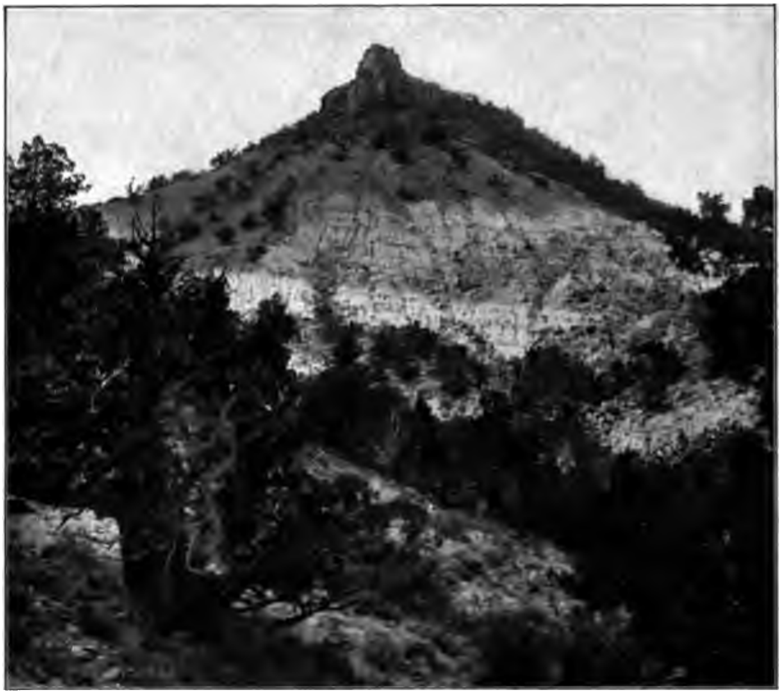
[a] Univ. California, Bull. Geol. Dept., vol. 2, pp. 299–314.



A. JOINTED RHYOLITIC TUFF AT SUMMIT OF LOGAN BUTTE, CROOK COUNTY.



B. LOGAN BUTTE, CROOK COUNTY.

Looking north.

frequently has a thickness of 40 feet, is massive and of a brown color, and at its base passes abruptly into a still more massive layer, which at times has the appearance of shale and is nearly black in color owing to the presence of numerous thin angular fragments of rhyolite with "perlitic" structure. The thickness of the lower division, where best seen, is exposed for 30 feet without revealing its base. The entire bed is frequently strongly jointed, the columns produced being at times as prominent as in the case of well-jointed basalt, the joints passing from one division of the bed to the other without change, thus showing both portions to be products of the same period of deposition. The differences in the two divisions of the layer are no doubt due to changes in the nature of the volcanic fragments which were showered on the land, and form the entire deposit. The absence of stratification in this and other similar sheets of volcanic débris, and also the fact that in some instances the thin, plate-like fragments entering into their composition stand on edge, are evidences that the tuff fell on land and is not a water-laid deposit. The difference just noted between the upper and lower portions of the tuff sheet in question is thought to furnish a means for identifying it at widely separated localities.

Artesian conditions.—In the central portion of Price Valley there are springs with a temperature of 67°. Near them two wells have been drilled, each of which reached water under sufficient pressure to cause free discharge at the surface. The record of one of these wells, furnished in part by Richard Hurley, is as follows:

Completed in 1885; bored with hand auger; diameter, 2 inches; total depth, 229 feet; reached water under pressure at 130 feet, which rose about 20 feet above the surface of the ground; discharge estimated at 12 cubic inches per second; water hard and tasted of sulphur; temperature, 73°; lower 100 feet of well yielded no additional supply of water; material passed through reported to be clay; owing to a disturbance of the discharge pipe on bending it, most of the flow was lost; water used for irrigation and farm purposes. The other well, situated about 380 yards northeast of the one just described, depth not ascertained, also yielded artesian water.

The structure of the sedimentary beds in Price Valley gives no indication of the presence of a synclinal basin—that is, the inclinations of the strata do not correspond with those found in such basins as commonly yield water under pressure. The temperature of the water, 73° F., indicates that it comes from a much greater depth than that of the boring through which it rises, and probably from at least 1,300 feet below the surface. These two facts favor the conclusion that a deep artesian basin, or other conditions favoring the storage of water under pressure, exists beneath the formations outcropping in the valley.

These two successful artesian wells, neither of which has been cased, and one of which gave an artesian head of at least 20 feet above the surface of the ground where it was drilled, are an assurance that other wells put down to a depth of about 150 feet in the portion of the valley where they are located would meet with equally favorable results. At a distance of over a mile from the existing artesian wells drilling will very likely have to be carried deeper than 150 feet, but hope of obtaining a surface flow should not be abandoned so long as soft rocks are met.

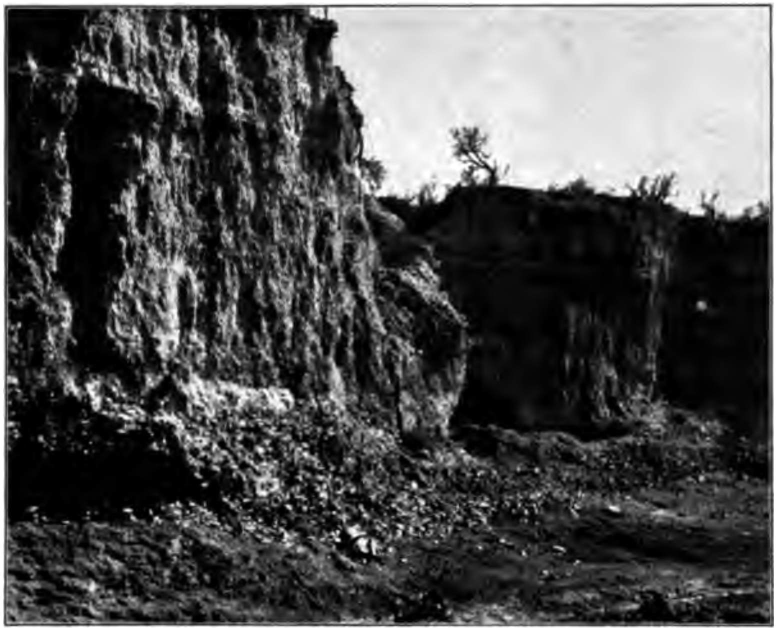
There is a large body of excellent land in Price Valley which can not be irrigated by means of surface streams, but which should be rendered of value by the presence of water under pressure at small depth, provided rigid economy and common sense are exercised in utilizing the supply.

Drilling in Price Valley, as has already been demonstrated, can be done with a hand auger to a depth of at least 200 feet, but each well put down should be properly cased, and if a surface flow is obtained the water should be shut off when not being utilized.

Recent erosion.—The floor of Price Valley, when seen from its north or south border, presents the appearance of a smooth sagebrush-covered plain. In crossing the valley, however, one finds that its surface is intersected by arroyos, or small canyons, through which water flows during the wet season. Joining the main trenches are several branches, each of which has the characteristics of a young stream-cut canyon. The main trench, which follows the longer axis of the valley, ranges from 60 to 100 feet in width, is approximately 25 feet deep, and has vertical walls throughout the greater portion of its course. The walls of the arroyos reveal admirable sections of the unconsolidated silts of recent date which floor the valley and, together with the recent erosion that has taken place, present facts of much interest. The appearance of the main trench about 2 miles east of Logan Butte is shown on Pl. VI, *A*.

The upper 17 to 20 feet of the arroyos' walls are composed of fine, gray, silt-like material which reveals obscure laminæ but no conspicuous stratification. Beneath the silt there is an irregular sheet of gravel from 0 to 6 feet in thickness, which rests on the eroded edges of layers of weathered shale like that exposed in the valley sides, and presumably belongs to the John Day formation.

The interpretation of the condition described is that Price Valley was excavated in the John Day beds, and then filled to a depth of about 20 feet with fine-grained, stream-deposited silt. The silt is a flood-plain deposit, the counterpart of which can be seen in many places along the borders of streams throughout the arid portion of Oregon. These deposits correspond in age and in mode of deposition with the adobe and related deposits of the Great Basin and of other portions of the arid region of the Pacific mountains. After the valley was filled to the depth stated a change occurred in the



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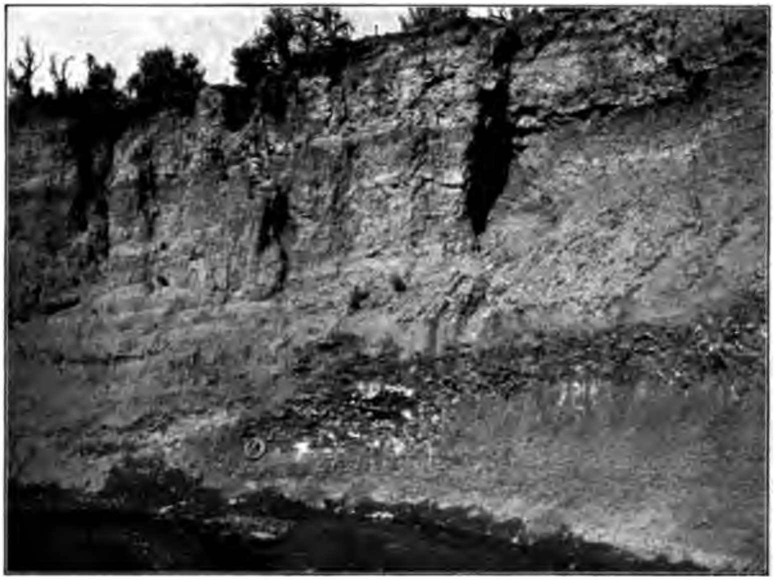

B

WALLS OF RECENTLY ERODED STREAM CHANNELS IN ALLUVIUM, NEAR PRICE, CROOK COUNTY

action of the streams. Instead of continuing to deposit silt and raise the floor of the valley, they began to erode, not only cutting through the soft bed of silt and the irregular sheet of stream-deposited gravel on which that material rests, but even in places excavating channels to a depth of 4 to 6 feet in the underlying Tertiary shales.

The change that caused the streams to excavate instead of deposit was certainly very recent, probably dating back only about fifteen or twenty years, although no note of its occurrence seems to have been taken by residents of the region. The renewal of the energy of the streams, however, is a part of a widely extended change, some account of which has already been recorded,[a] and probably coincides with the introduction of domestic animals in such numbers that the surface covering of bunch grass was largely destroyed, and in consequence the run-off from the hills accelerated.

HAMPTON BUTTE.

Rising boldly from the northeast border of the Great Sandy Desert, in the southeastern portion of Crook County, is a much eroded volcanic mountain known as "Hampton Butte." When the geologic story of central Oregon is written, this butte, together with the Glass Buttes of similar history, 15 miles to the southeast, will occupy a leading place, since each of these elevations was built by explosive volcanic eruptions which discharged acid lavas and, as seems probable, furnished much of the material for the formation of the widely extended tuff sheets which form the surface over hundreds of square miles of the adjacent country. In the history of each of these ancient volcanoes there are two prominent chapters, one dealing with their construction or upbuilding and the other with their destruction or erosion.

GEOLOGY.

Hampton Butte has an elevation, as determined by aneroid measurements and subject to probably important corrections, of about 2,500 feet above the nearly level surface of the broad desert plain to the south. Its base is irregular in outline, owing principally to the deep dissection of its sides by stream erosion, but in general measures about 6 miles in diameter. The butte has three prominent summits, the one farthest southeast, on the site of the mountain's peak when in its prime, is higher than its companions. It is composed of massive andesitic lava, and is the deeply eroded summit of the column of rock that cooled and hardened in the conduit of the volcano. The peak about 1 mile distant to the west of the central core is also of solid lava, but seems to be part of a lava flow; and the prominent ridge about 1 mile north of the summit, like the greater part of the butte, is composed of volcanic agglomerate. On all sides of the butte, forming its widely extended slopes, are beds of stratified agglomerate, which dip away from its central portion in all directions at angles in general of from 3 to 5 degrees. The dip of these beds decreases with distance from the vent from which the material composing them was blown out, and the component fragments show a decrease in size in the same directions. The agglomerate exposed in the border of the butte at a distance of 2 or 3 miles from its summit, consists largely of angular blocks of light-colored lava ranging from 2 to 4 feet in diameter, firmly held in a compact matrix of angular volcanic sand and gravel. It weathers into monumental forms, admirable examples of which occur on the northeast side of the butte overlooking Gilchrist Valley (Pl. VII) and at many other neighboring localities. The thickness of the agglomerate beds on the sides of the butte is not less than 1,200 feet, though a full measure was not obtained.

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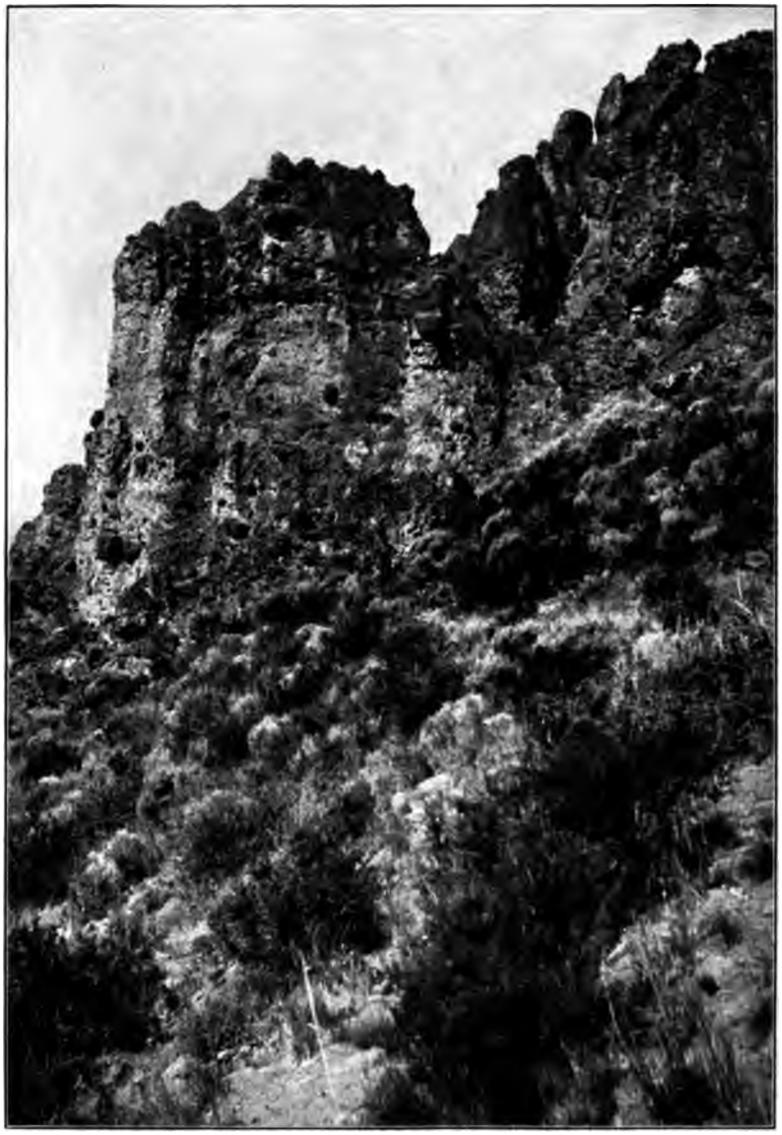
[a] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 145-146.

An exception to the statement that Hampton Butte is composed of andesitic lava and fragmental material of the same nature occurs on its southeast side, and in a neighboring but intimately associated ridge, sometimes termed "Cougar Butte," in which black rock resembling basalt is well exposed. The eruptions which furnished the black rock were evidently later than the period of activity of the andesitic volcano which built the main portion of the mountain, but their full history remains to be studied.

The records now exposed and clearly legible show that Hampton Butte was at one time a conical mountain much higher than at present, and as may be judged from analogy with other similar volcanic piles that are yet in their prime, formerly had a crater with an encircling rim of lapilli at its summit. All vestiges of such a crater have disappeared, however, and the once smooth, sweeping slopes of the conical pile have been deeply trenched by streams which flowed away from its central portion in all directions. Ten or twelve gulches carved by these streams still lead downward to the bordering plains. The butte now presents a rugged surface; nearly everywhere the soil is composed of light-colored volcanic sand, containing many loose blocks, and has been formed principally by the disintegration of the agglomerate beds on which it rests. The rain that falls is at once absorbed and surface rills are uncommon, but cold springs come to the surface in most of the gulches and, as noted below, have an instructive relation to the stratification of the beds from which they issue. The hills and the valleys alike are clothed with luxuriant bunch grass and the north sides of several of the ridges bear beautiful groves of yellow pine, showing a delicate adjustment in the



ANDESITIC AGGLOMERATE ON EAST SIDE OF HAMPTON BUTTE, CROOK COUNTY.

distribution of soil moisture. Less restricted in their distribution than the pine and extending far out on the bordering plains are open growths of juniper trees.

WATER RESOURCES.

Hampton Butte is not not only isolated in reference to its associated mountains, but is also remote from centers of industry and far removed from usual routes of travel. On the north its nearest neighbor of comparable prominence is Mutton Mountain, about 12 miles distant, and on the southeast the Glass Buttes, about 15 miles away, across a nearly level sagebrush plain. In all other directions comparable elevations are remote. There are a number of cabins about the butte, all occupied by energetic and most hospitable ranchers. The watering places have been inclosed by fences, and small areas about the lower slope of the butte are irrigated and produce good hay crops and some wheat. The value of the butte and the region about it, however, lies almost solely in its excellent pastures, its usefulness as a stock range being due largely to the fact that it is an outpost of industry in a generally waterless land. To the south the great desert, which in winter furnishes abundant pasturage, extends without a resident for 40 or more miles, while the butte itself is so thinly settled and the extent of the uninhabited country about it so vast that it is still almost in a state of nature. Its grasses are still luxuriant, and deer and antelope continue to make it their home; mountain sheep were formerly abundant, but have now vanished.

The remoteness of Hampton Butte from all commercial centers, the abundance of grass on its hills and vales, the number of its cool refreshing springs, the beauty of its groves of whispering pines and junipers, and, perhaps more than all, the almost continuous sunshine that bathes its breezy slopes, make it wonderfully attractive to the traveler, from whatever land he may have wandered. As a health resort and place of rest and recreation it has but few rivals.

Springs.—Hampton Butte, as stated above, is located in an arid region and in the midst of broad plains on which there is scarcely any perennial water. The demand for water is very great, not only for irrigation, but for watering stock and for household purposes. To meet this demand the only source of supply now utilized is the scanty outflow from springs.

About the butte, at an elevation of approximately 5,000 feet above the sea, or 1,000 feet below the highest summit, there are several springs, for the most part of small volume. They are located in gulches eroded in the outward-dipping sheets of agglomerate and tuff which surround the central plug of lava, and come to the surface where retentive strata outcrop. The retaining layers, as indicated in at least two instances, are thick beds of coarse but firmly cemented agglomerate. On account of the dip of the beds of agglomerate and the manner in which radiating gulches have been excavated in them, the more resistant beds extend far toward the summit of the butte on the crests of the ridges between the radiating gulches, in the bottom of which their lowest outcrops occur. The springs are all cold, their temperature being from 51° to 53° F., and their source of supply is clearly the rain and snow that falls on the butte above the outcrops of the retentive layers, which cause the water to appear at the surface.

The conditions just described render it evident that something can be done in the way of improving the springs and conserving the water that now percolates away and is lost. The best method of doing this is to excavate tunnels in the rocks, beginning a few feet, or rather as low as practicable, below where a spring now appears and continuing the excavations toward the center of the butte with a gently rising gradient until the retentive bed is passed through and more porous material reached. The tunnel should then be extended in two branches, like the arm of the letter Y, so as to intercept and furnish a free escape for the percolating water. The length of the main tunnel in each instance would have to be governed by local conditions, and chiefly by the thickness and dip of the retentive layer of agglomerate to be penetrated, but in no instance, so far as can now be judged, would an extent of more than 300 or 400 feet be required. Suggestions as to this method of utilizing what may be termed horizontal wells have been presented in a previous report.[a] Several if not all of the springs about Hampton Butte might be improved in the manner just suggested and the available water supply considerably increased. The main or entrance tunnels in each case should be floored with impervious material, as clay or cement, and the water obtained conducted in pipes to the localities where it is to be used. This method of utilizing the water in the case under consideration is especially recommended, since the localities where it can be employed are well separated one from another, and each rancher owning a developed spring would not be in danger of having his water supply drawn upon by his neighbors, and hence would in his own interest be led to the utmost economy in its use.

In place of excavating a tunnel, as suggested above, at each of the localities where a spring appears in a well-defined gulch, a similar end can be reached by drilling a vertical well a few yards or a few rods downstream from the locality where water now comes to the surface. Such drill holes, if carried to a depth of about 250 or 300 feet, should in most instances yield flowing water. It is not possible at present to state just how deep such drill holes should be carried, but the conditions are favorable, and the depth mentioned might reasonably be attempted unless success is secured sooner.

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[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 54, U. S. Geol. Survey, 1901, pp. 98–101.

As already explained, the stratified tuffs and agglomerates forming the greater part of Hampton Butte dip away from its central portion and decrease in their degree of inclination with increase in distance. The size of the fragments composing the beds also decreases with the distance from the vent from which they were discharged. These conditions favor the hope that artesian water can be had about the outer border of the butte. On its north side there is a lake basin, or rather water pocket, several hundred acres in area, about which, particularly on the southeast, there are several square miles of nearly level sagebrush land. This locality is sufficiently near Hampton Butte to favor the hope that artesian water can there be had, owing to the outward dip of the beds of tuff, etc., as just explained. There does not seem to be any way to test this possibility except by means of the drill, but the value of a flowing well at the locality referred to would be sufficient to warrant giving weight to the known favorable conditions. After due consideration I venture to suggest that it would be well to put down a drill hole at the locality mentioned to a depth of at least 1,000 feet.

When the several springs about Hampton Butte are developed so as to yield their full quota of water it is to be expected that practically all the irrigable land immediately below them can be converted into hay ranches. The actual areas of such irrigable lands have not been computed, but are well known to the ranchers of the vicinity, and, although small in each instance, are of great value in the aggregate from the use to which the hay can be put in the feeding of stock during unusually severe winter weather. Summer pasture is abundant, but the critical condition that limits the number of head of stock a rancher can safely maintain is the necessity of tiding them over the stormy periods of winter. Hence every effort should be made to increase and conserve the limited water supply.

Water pockets.—The extent of country over which stock can range about Hampton Butte, as is the case throughout the arid region, depends on the presence of watering places. With a wide summer range, the grass near winter supplies of hay can be conserved, and thus greater benefits be derived from it. As summer watering places in the valleys and on the plains about the buttes are far apart, a suggestion offered on page 53 in reference to deepening natural water pockets may here be repeated. At Dry Lake, as it is termed, referred to above, situated about 6 miles north of the butte, a reservoir could be excavated which would contain sufficient water to supply a large number of cattle throughout the summer. The advantage of excavating a reservoir to as great a depth as practicable may be readily judged from the fact that water now stands in the basin each spring to a depth of a few inches over an area of a square mile or more. By restricting this supply to a smaller area the loss from evaporation would be lessened and the duration of the supply increased; besides, an excavated reservoir would serve as a well and lead to the percolation to it of the ground water from adjacent areas.

The plans outlined above for the increase and concentration of the water supply about Hampton Butte call for only small investments, such as the returns to be expected amply justify, and I trust will receive careful consideration from the intelligent and progressive ranchers of the locality.

GREAT SANDY DESERT.

HAMPTON BUTTE TO BUTTON SPRING.

The route followed on leaving Hampton Butte led southwest across the Great Sandy Desert toward Christmas and Silver lakes. The first water met, with the exception of a small ephemeral lake, or "pocket," of alkaline water unfit for human use, occurs at Button Spring, about 35 miles from the west base of Hampton Butte.

For about 4 miles from the springs on the west side of Hampton Butte the country rock is andesite and andesitic tuff similar to the material composing the butte itself, from which it probably came. Judging from the topography, this same rock extends far to the northwest. At a distance of about 6 miles from Hampton Butte, however, in the direction mentioned, is a low conical elevation, which, judging from its color as seen at a distance, is composed of basalt, and about it is an extensive lava flow of the same character. The butte referred to is on the "upper desert;" that is, it lies to the north of the long line of bluffs that form the northern border of the Great Sandy Desert, or the "lower desert," as it is locally termed. This line of bluffs, which sharply defines the north border of the Great Sandy Desert for fully 20 miles northwest from near the south base of Hampton Butte, is composed of sheets of basalt, the eroded edges of which reveal a thickness of between 80 and 100 feet. The beds are gently inclined and dip northward at an angle of about 1°. In places the steep escarpment is concealed by pumiceous sand, which has been drifted over it by the prevailing westerly winds.

On descending this south-facing escarpment of basalt through a notch that seems to have been eroded by a south-flowing stream the nearly level surface of the lower desert is reached; thence southwestward the road follows an almost straight course bearing S. 25° to 30° W. for about 15 miles across a plain of light-colored pumiceous sand, with occasional exposures of basalt. The outcropping layers of basalt dip north at a low angle, probably 1° or 2°, until the axis of the valley is passed, at a distance of 5 or 6 miles from the line of bluffs bordering it on the north. This dip is revealed in the gradient of the road, which, when followed southward, ascends long, gentle slopes, at the top of each of which is a short, steep descent to the base of another gentle rise. The beds of basalt on the south side of the valley for several miles, although seemingly nearly horizontal, have a gentle downward slope to the south. From the facts noted along the section traversed in crossing the Great Sandy Desert, that depression appears to be of the nature of an anticlinal valley; that is, it has been eroded in the summit portion of a gentle upward fold or anticline.

The Great Sandy Desert is without water, except such as gathers in small basins and forms water pockets during the winter. Wells dug, as I have been informed, to a depth of about 70 feet failed to reach water, the material passed through, like that forming the surface, being pumiceous sand. No method of obtaining water on the desert, even for stock ranches, seems to be practicable, except the deepening of the natural water pockets. So far as the geologic structure is known, it gives no suggestion of the presence of artesian conditions.

On the southwest side of the Great Sandy Desert, or in a general way about 25 miles north of Christmas Lake, there are a large number of low and for the most part rounded buttes, each of which marks the site of an old volcano. This region, like the arid plain adjacent to it on the north, is without water, and, as is manifest from the number of volcanic cones present, as well as the apparent absence of the necessary geologic structure, offers no encouragement to the searcher for artesian water.

BUTTON SPRING.

Button Spring is located about 15 miles northwest of Christmas Lake, and with the exception of two or three wells that have been dug near the road between these two localities, is the only available water within a radius of 15 miles, and in most directions of 30 or more miles. To the east of the spring extends a waterless region without trees, except an open growth of junipers, but on the west the country is shaded by a magnificent forest of yellow pine, which continues west over a region rendered rugged by many recent basaltic craters and several mountain-like elevations eroded from more ancient andesitic lavas, to the Cascade Mountains and thence to the shore of the Pacific. The forest terminates abruptly on the east in what may be designated as a dry timber line. The grass on the eastern border extends into the forest, forming beautiful glades, and grows luxuriantly beneath the trees, but the absence of water renders these natural pastures useless. Great as is the demand for water in this inviting region both for stock and, as will no doubt soon be the case, for sawmills, no practicable method of supplying it can at present be suggested, except that small storage reservoirs might be made in some of the valleys.

Button Spring is a weak hillside spring which emerges at the base of a rim rock of basalt on the side of a small valley. The volume of the spring was formerly greater than at present, and, as is reported, served for the irrigation of a few acres of land, but attempts to increase the supply by excavating a vertical well resulted in a loss of the water. The well is said to have been 100 feet deep, but it has now been filled to within a few feet of the surface. The excavation reached a light-colored, highly porous layer, probably of volcanic dust, beneath the surface sheets of basalt, thus permitting of the ready escape of the water. Much water is evidently still being lost in this way, but the value of the spring can no doubt be restored by placing a water-tight floor or shallow cement basin in the bottom of the excavation as it is at present and allowing the water to flow out as formerly. The excavation of a horizontal and not a vertical well would have been the proper method for developing the spring.

LAVA CAVES.

About half a mile east of Button Spring there is a locality where the falling of a portion of the roof of a cavern has formed an opening about 14 feet across, by means of which access can be gained to a subterranean chamber of the ordinary type of lava tunnels, formed by the outflow of molten lava from beneath the thick, rigid crust of a sheet of basalt. The tunnel on which the opening is located trends east and west, but owing to the falling of parts of its roof can be followed for only a few rods. The opening leading down to the cavern suddenly expands about a foot below the outer surface into a vaulted chamber approximately 100 feet in diameter and 45 to 50 feet deep. Snow entering the chamber through the hole in the roof remains until late summer, and, as persons familiar with the region state, sometimes endures, in part changed to ice, from one winter to the next. A little ice was present at the time of my visit, July 29, 1903, and the temperature of the air in an extension of the main chamber and at a depth of 40 to 60 feet below the surface was 49° F. This opening may therefore be termed an ice cave, and, like others in the same general region, may be considered as a natural ice house, in which the presence of ice is due to the preservation of snow and ice formed during winter months.

In the vicinity of the cavern just described there are irregular, steep-sided, canyon-like valleys from 40 to 50 feet deep which owe their origin to the subsidence of the roofs of similar lava tunnels.

BASALTIC CRATERS.

All about Button Spring there are conspicuous buttes, mostly with rounded summits, which by their shapes at once declare their volcanic origin. These hills, of which typical examples are shown on Pl. VIII, are old volcanic cones composed of basaltic lava, for the most part in the form of lapilli and scoriæ, usually of a reddish color, and to a minor extent of well-formed bombs. In a few instances they extruded lava in streams that spread out in sheets on the adjacent plain. In most cases the cones have yielded to the weather to such an extent that the craters which once existed in their summits have disappeared, and their tops have been fashioned into dome-like shapes, in most instances presenting examples of what are termed weather curves. From a hill near Button Spring 28 individual volcanic craters were counted within a radius of about 7 miles, lying mostly to the east of the place of observation. Many other similar volcanoes are also known to exist in the forested region to the west of the same locality and still others to the south. The majority of the old craters are small, ranging in height from 150 to 200 feet, but some of those to the southeast, as noted below, are much higher.

These elevations furnish good illustrations of the weathering of accumulations of porous material, such as scoriæ and lapilli, in their passage from a conical shape with steep sides to rounded hills and gently swelling mounds. An instructive fact in connection with the weathering of cinder and lapilli cones is that they sometimes give origin to crescent-shaped and even nearly straight ridges which are steep on one side and slope gently on the other. In the case of the crescent-shaped ridges the steep slope is on the concave side. Such weathered remnants find an explanation in the form of the original piles, due to the agency which built them and in some instances partly destroyed them. A symmetrical volcanic cone composed of scoriæ and lapilli changes under the destructive action of the atmosphere to a symmetrical mound which expands and flattens as weathering progresses, while a crater, one side of which has been blown away or removed by an outflowing lava stream, weathers to a crescent-shaped hill. If the destructive action of the volcanic agencies has been greater and only a fragment of a comparatively large crater wall is left standing, it sinks as weathering progresses into a ridge, at the same time broadening, owing to the removal of material from the summit and its deposition on the sides and about the base of the pile, finally becoming a ridge in which the original curvature of the longer axis may be entirely lost.

The weathering of the volcanic piles near Button Spring has brought out still another feature which is not uncommon in the topography of ancient craters. In the case of a small cinder cone about 1 mile east of the spring a lava flow originated in a summit crater, descended the northeastern slope of the cone, and reached the plain at its base. The portion of the lava stream which cooled and hardened on the side of the cone forms a sheet 30 to 50 feet thick and 400 or 500 feet wide, inclined at an angle of approximately 20°. After the lava hardened the crater from which it came was deeply eroded and all vestiges of its rim removed, leaving the upper portion of the lava stream in bold relief as the highest part of the unsymmetrical hill of which it forms the steepest side. A photograph of this instructive butte is presented in Pl. VIII, *A*. The margin of the lava sheet facing the site of the crater from which it came is precipitous and its lateral margins are also bold. As weathering continues, it is to be expected that the solid lava will become more and more prominent until at a late stage all vestiges of the cinder and lapilli cone from which it came will have disappeared. It will then be left as an isolated inclined bed, with a gentle slope on one side and a steep talus on the other; that is, it will have the appearance of a local uplift of a portion of a previously horizontal sheet of basalt.

The sequence of topographic changes just outlined may be illustrated by a series of ideal examples, as in the following figure, which shows stages in the change referred to:

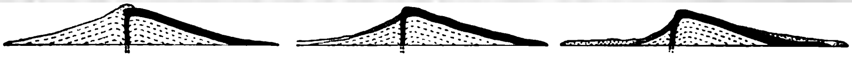
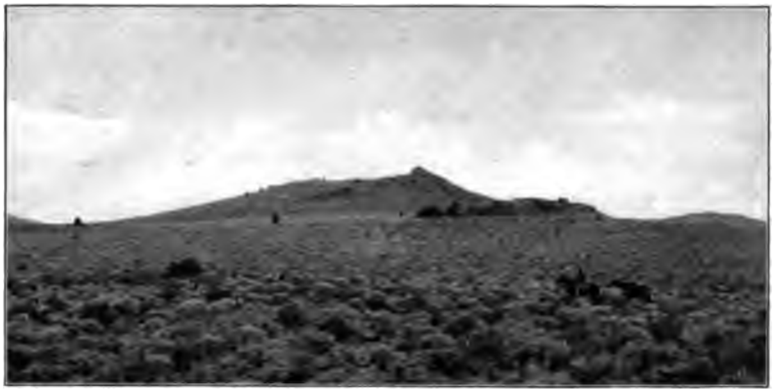


FIG. 1.—Sketch of cinder cone with summit lava flow.

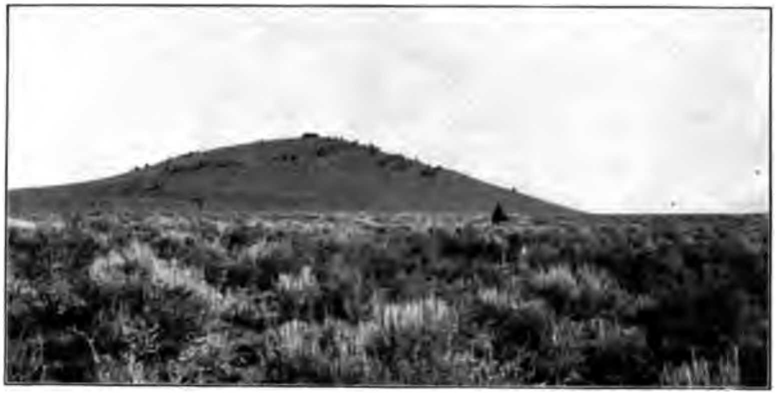
The sketches represent vertical sections through a cinder cone from which a summit discharge of liquid lava occurred at various stages during its erosion. The first sketch to the left represents a section of the young crater, and the succeeding ones the changes passed through up to the time the cinder cone has mostly disappeared, and only the inclined sheet of more resistant lava remains.

Not only are inclined sheets of solid lava left exposed by the erosion of the cinder and lapilli craters from which they were discharged, but, as is suggested by some of the craters near Button Spring, the tuff beds on one portion of a crater may be more resistant than other portions of the same accumulation and be left, as erosion progresses, as isolated inclined beds. As it seems, also, flows of brecciated or angular fragmental material simulating true lava streams in the manner of their extrusion are sometimes discharged from summit craters and descend their outer slopes. Such outpourings also may endure as local exposures of inclined beds when erosion has removed the cones on which they originated.

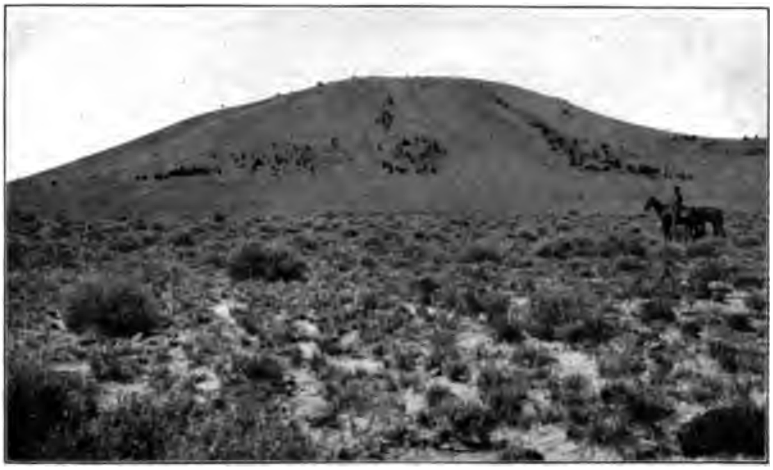
The weathering of a cinder or lapilli cone, from which a stream of lava has been extruded from a summit crater, in the manner de-



A



B



C

BASALTIC CINDER CONES NEAR BUTTON SPRING, LAKE COUNTY.

A, With summit lava flow, *B*, with residual mass of tuff at summit, *C*, weathered cone.

scribed above, furnishes an explanation of the nature of certain curious buttes in Oregon and Idaho, which have been a puzzle to all who have seen them. For example, some 10 miles northeast of Button Spring there is a butte about 250 feet high, which has an inclined table on one side and is locally termed the Soldiers Cap, in reference to its resemblance to the caps worn by Union soldiers during the civil war. Although I have seen this butte only from a distance, it appears to be of the nature of the cone near Button Spring, described above, but in a more advanced stage of erosion. Again, on the north border of Snake River, about 12 miles south of Caldwell, Idaho, there is a conspicuous butte about 125 feet high, which has an inclined table on its eastern side, and is apparently another example of the same nature. A third illustration is furnished by Middle Butte, situated midway between East and Big buttes, on the Snake River Plains, about 28 miles northwest of Blackfoot, Idaho. In this instance a sheet of basalt 100 feet or more thick rises boldly from the plain with a slope of about 10° toward the southeast, and breaks off in a precipitous escarpment on its northwest border. The butte is about 500 feet high, approximately a mile long from northeast to southwest, and about half a mile wide. Surrounding it on all sides is a plain of basalt of more recent date than the rock of which it is composed. This example of what appears to be a local uplift may well be a large example of a lava stream on the side of a cinder cone that has been left isolated by the erosion of its parent crater; in this instance, however, subsequent basaltic flows from neighboring craters have assisted in concealing evidence of the cinder cone from which the inclined sheet of lava was probably erupted. This same hypothesis seemingly furnishes an explanation for the presence of the inclined sheet of basalt referred to in describing Hampton Butte, designated on the General Land Office map of Oregon as Cougar Butte, but locally considered as a part of the large butte to the northwest.

The several examples just referred to were seen by me before I visited the butte near Button Spring, and were passed by without being understood; now they seem to be explainable on the hypothesis here presented.

BLACK MOUNTAIN.

From any commanding point of view near Button Spring the most conspicuous elevation in sight is a prominent black butte with a triple summit, about 8 miles to the southeast. As seen from the direction just mentioned the cathedral-like elevation consists of a central dome about 800 feet high, flanked on each side by smaller domes approximately 200 feet lower. The grouping of the three is strikingly symmetrical, and their slopes descend to the black lava field which surrounds them in long, sweeping curves. The blackness of the group, which has suggested its name, is due to the color of the basaltic lava of which it is composed, but has been enhanced in recent years by the burning of the open forest that clothed its sides and extended over the surrounding lava flow. A younger forest has sprung up, however, and now the lava field and central elevations are overgrown with junipers, mountain mahogany, and a few pines.

On visiting Black Mountain the symmetry of the grouping of its three central domes is found to depend on the point of view from which they are observed. The central elevation is composed of coarse lapilli and scoriæ, among which a few well-shaped volcanic bombs occur, but it is only a remnant of the original crater. The part remaining is the northern portion of the rim of a bowl-shaped depression, about three-fourths of which has been removed, the outline of the missing portion being indicated by low ridges of lapilli. The crater seems to have been breached by an outflow of lava from its southern side, but may have been ruined by an explosion. The west elevation is closely connected with its higher companion, and is a lapilli and scoriæ crater 100 feet deep with a complete rim about 450 feet in diameter. The southeast elevation, which appears as a rounded dome when seen from the north, in close proximity to the central elevation, is in reality about three-fourths of a mile distant and is but the ruin of a crater composed of reddish scoriæ.

All about Black Mountain there is a fresh basaltic lava field, with an irregular margin, in general from 1½ to 2 miles in radius. This lava came to the surface near the base of the central crater, and perhaps represents the results of more than one eruption. Its surface is fresh in appearance and excessively rough. On its margin it terminates in steep, irregular escarpments. The roughness of the surface and the steepness of the bordering slopes show that the rock of which it is composed flowed out either in a highly viscous condition or that its motion was retarded by the fragments of the first-formed crust which became involved in and were carried along by the still viscous material beneath and into which they sank. The surface slope of the lava field is between 2 and 3 degrees near the the craters with which it is associated, but at a distance of less than half a mile flattens out and becomes essentially horizontal. On its northern portion there is a group of small, fresh-looking craters, probably produced by superficial explosions.

From the summit of Black Mountain an instructive view is furnished of a land dotted with craters in various stages of erosion, of which about 25 still retain enough of their characteristic constructional shapes to be recognized as being of volcanic origin. On the east the bare mud plain about Christmas Lake, in places white with salt and other efflorescent products, is in view. The entire landscape eastward of the mountain, and extending for a score of miles on each side of the desolate plain in its midst, is typical of the arid region of which it forms a part. This is the northern extension of the Great Basin and is similar to the vast expanse of arid country embraced in the series of drainless basins in Nevada, Utah, etc., with which it forms a connected series. On the west occur many recent basaltic craters and more ancient hills and ridges that have resulted from the dissection of light-colored andesites and rhyolites; all are covered by the great pine forest to which reference has already been made.

GENERAL GEOLOGY.

In traveling toward Button Spring from Hampton Butte, all the solid rocks exposed, after reaching the line of basaltic cliffs, described on page 68, which defines the northern border of the Great Sandy Desert, are basalt. To the east and south of the spring also nothing but basalt was encountered in the various excursions made from that locality, and the many old craters in sight from Black Mountain and other neighboring eminences, within a radius of about 10 miles, are dark in color and appear to be composed of basaltic rocks. On the west of the spring also several basaltic craters were visited, and others recognized by their color, mode of weathering, etc. All of this goes to show that basaltic eruptions from many craters have there taken place. The number of craters in various stages of erosion and decay within a radius of 10 miles from Button Spring is by estimate not less than 50. Beginning about 2 miles south of the spring and extending far into the forest to the southwest are abundant outcrops of light-colored lavas (andesites and rhyolites) and variegated tuff beds, which contain large masses of black obsidian. These rocks weather into bold cliffs and have been deeply trenched by stream-cut valleys, now without water except in winter or when the snow is melting, and in many instances without rill channels in their deeply filled and nearly flat bottoms.

The region about Button Spring contains the records of at least three groups of events: First, a prevalence of volcanoes, probably in the early Tertiary age, which discharged acid lavas and were characterized by the violence of their explosive eruptions; second, a long period of denudation, during which the previously formed lava flows and tuffs were deeply eroded (this time seems to relate in part at least to the Sierran epoch), and, third, a modern period, during which a large number of volcanic vents were established and basic lavas extruded, both during explosive eruptions and quiet discharges of liquid rock. These recent basaltic volcanoes, although comparatively young and furnishing the last important chapter in the geologic history of the region, are actually centuries old, and in most instances have suffered much defacement from the attacks of the denuding agencies of the air. The later chapters in this interesting geologic history, when fully interpreted, will include an account of a climatic change from humid to the present arid condition.

From Button Spring a road leads north to Prineville, on following which one passes over basalt nearly all of the way. Rocks that are older, however, and that differ in character from the seemingly universal sheets that floor the valleys, form the three prominent groups of hills, namely, Pauline Mountains, Pine Mountain, and Powell Butte, which were visited during the journey. In places, as midway between Button Spring and Pine Mountain, the basalt forming the plains is concealed beneath an extensive series of dunes composed of pumiceous dust and lapalli.

DRY RIVER.

Our first camp after leaving Button Spring was in the bed of an ancient stream known as Dry River, which at one time drained the Great Sandy Desert. The course of the channel is well marked from the west end of the desert to Deschutes River, a distance of over 50 miles. At our camp, about 6 miles east of Pauline Mountains, the old river bed is a well-defined canyon, 30 to 40 feet deep and 150 feet wide, with walls of columnar basalt. About 12 miles farther west the canyon becomes deeper, and for a distance of 4 or 5 miles is a narrow defile with vertical walls of basalt. In the river bed at the time of our visit there was no water, but by digging in the sand that partly fills the channel a sufficient supply for camp purposes for a single day was obtained at a depth of 6 feet.

PAULINE MOUNTAINS.

The name Pauline Mountains is used on the General Land Office map of Oregon to designate a prominent group of hills situated 42 miles directly south of Prineville and approximately in the geographic center of the State. Locally, however, the same name is also applied to other equally conspicuous elevations in the vicinity of Pauline and East lakes. Although these two groups of picturesque hills or mountains are connected by a tract of high land, they are independent, so far as their geologic histories are concerned, and as they will no doubt receive much attention from geologists and others in the future, it is thought advisable to designate them by separate names. For the group of hills termed the Pauline Mountains on the map referred to above that name will be used in this report, and for the exceedingly interesting and conspicuously beautiful mountain in the summit of which Pauline and East lakes are situated a special name will be proposed on a later page (see p. 97).

The Pauline Mountains proper rise boldly from the bordering basaltic plain to a height of about 1,500 feet. The main summit is a sharp ridge trending N. 70° E. (magnetic), which at each end curves abruptly southward, so as to partly inclose an amphitheater nearly 2 miles in diameter. The rock along the crest of the ridge and forming the conspicuous pinnacles rising from it is a hard, purplish material resembling quartzite, but from field observations simply is believed to be mainly a consolidated rhyolithic tuff. The sides of the mountain are thickly covered with quartz sand. The stratification of the rock is well defined and the dip on the crest of the main ridge is downward to the east at an angle of about 16°, the strike being at right angles to the trend of the ridge. In the curved western portion of the ridge, and exposed in the west wall of the great amphitheater, the dip is south at an angle of from 16° to 17°. The mountain is thus shown to be an eroded remnant of what was probably at one time a great volcanic cone older than the surrounding basalt, but no fossils were discovered by means of which its age might be determined. To the northwest of the main ridge and about half a mile distant rises an outstanding butte composed of rock of the same character as the main elevation, left in bold relief by erosion.

The floor of the amphitheater on the south side of the Pauline Mountains is deeply covered, over an area of 3 or 4 square miles, with nearly white pumiceous lapilli, which the wind has drifted into dunes. This barren area is bordered on the south by an open forest of junipers. The mountain itself, more especially its northern slope, bears groves of yellow pine and has a well-defined forest about its western base.

The view from the topmost pinnacle of Pauline Mountains is far-reaching and superb. In the east, beyond the barren yellow plain of the Great Sandy Desert, Hampton and Glass buttes are in plain sight, and the tapering summit of Placidia Butte can be recognized in the blue distance. To the south, in the vicinity of Button Spring, about 50 recent volcanic craters can be counted, and in the western sky rise the snow-clad summits of several of the great peaks that dominate the generally even crest line of the Cascade Mountains.

POWELL BUTTE.

In the extensive region drained by Crooked River to the east of Prineville there are numerous hills, which, in places, are sufficiently bold and lofty to merit the name of mountains. These uplands for a distance of about 30 miles south of Prineville terminate abruptly on the west, where they meet a seemingly level but in reality gently westward-sloping plain of basalt. The junction of the hills with the plain resembles the margin of a rugged land adjacent to the ocean, except that the hill descends to the lava without change of slope such as the ocean's waves produce in the land. This resemblance to ocean-shore topography is due to the fact that extensive inundations of basaltic lava have partly filled a wide valley and encroached on its indented border. The lava flows extended up the gorges and ravines in the border of the old valley, leaving the ridges between them to project as capes into the black plain formed by the congealing of the lava flow.

Offshore, so to speak, in the once molten sea, about 4 miles from the nearest cape on the border of the uplands to the east, rises an island-like butte, completely surrounded by the lava plain. This conspicuous elevation, known as Powell Butte (not Paul Butte, as given on the General Land Office map of Oregon), is about 7 miles long from east to west and approximately 5 miles wide from north to south, but its margin is irregular, owing to the deep sculpturing which preceded the outflow of basalt which surrounded it and entered for short distances the high-grade valleys eroded in its sides. The butte rises, by aneroid measurements, 1,500 feet above the surrounding plain. The material from which it has been sculptured is a hard, resistant rhyolitic tuff, with, perhaps, some quartzite. The rocks are of a brownish and purplish color, weathering on steep cliffs to a rich brown. The bedding is distinct and steeply inclined. Inclinations of from 65° to 70° to the southwest are common, and in places the outcrops are vertical, with a northwest and southeast strike.

The facts just stated show that Powell Butte is a remnant of an ancient upland, which was deeply eroded before the coming to the surface of the extensive basaltic lava flows which now form the floor over an extensive portion of the valley of the Deschutes. In all of these features the butte resembles another rugged island in a congealed sea of lava, situated in the State of Washington and known as Steptoe Butte, some account of which is already on record.[a] This last-named butte is typical of the topographic features and geologic history which it illustrates, and all similar island-like areas surrounded by lava flows may for convenience be termed "steptoes." Powell Butte, therefore, on account of its isolated position and the fact that it rises through the lava of the encircling plain, may be designated a steptoe.

The sides of Powell Butte, particularly the bottoms of the gulches in its sides, are covered with fine rich soil, which owes its origin in large part to the deposition of dust by the wind. In the gulches this material has been washed down by ephemeral streams and spread out in broad alluvial fans with conspicuously inclined surfaces, which descend to the surrounding plain. These alluvial fans in certain instances are not scored by stream channels, and when cultivated yield good harvests of wheat without the aid of irrigation. At the heads of a few of the gulches small, cool, hillside springs come to the surface and furnish a water supply for household uses and for the watering of stock. The only method of increasing, or rather of conserving, the meager water supply is to excavate horizontal wells where springs appear, in the manner suggested on page 66, but owing to the excessive hardness of the rocks, the practicability of such a method seems doubtful. Water is now obtained at several localities about the butte by means of ordinary dug wells, and nothing need be said concerning the possibilities in that direction, as they are well understood by the few energetic, and for the most part successful, ranchers of the region.

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[a] Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, pp. 38–40; Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, pp. 19–pp.

DESCHUTES PLAIN.

Powell Butte forms one of the succession of admirable observing stations previously referred to as extending from east to west across eastern and central Oregon, and when the country is surveyed will furnish a favorable primary triangulation station. From its summit the view westward is particularly instructive. The plain of basalt which surrounds its base can be traced as on a map far to the west, across the seemingly level valley through which Deschutes River flows, to the base of the Cascade Mountains. To the southwest, 15 miles distant, across the level lava plain, rises the conical summit of Pilot Butte, an old volcanic cone, also a steptoe. Still farther south a widely extended group of recent volcanic cones can be recognized. The great plain of basalt also extends far to the northwest, and about 7 miles away meets a bold ragged crag of light-colored rock, which projects into it from the east. Crooked River here touches the high land bordering the basaltic plain, and for a distance of about 2 miles has cut away its base and caused a precipitous escarpment to appear. The area of the plain of basalt in sight, although not accurately known, is by estimate not less than 2,000 square miles. One seems justified in concluding that the basalt covering it is a southward extension of the vast lava flow of Washington and northern Oregon, to which the general name Columbia River lava has been applied. Previous estimates of the area covered by these lavas place it in the neighborhood of 250,000 square miles, but seem too conservative to an observer standing on Powell Butte who has in mind the various records previously made and remembers the notes presented in this report concerning the occurrence of similar rocks, which extend almost continuously from Steins Mountains on the east to the Cascade Mountains on the west. It is to be understood that the name Columbia River lava is a general term by which to designate the great basaltic lava flows of the Northwest, and that, as is well known, the various sheets of once molten rock range in age from the earlier portion of Tertiary all the way up to recent time. A detailed study, as the general reconnaissances already made clearly show, will necessitate the recognition of several independent formations, separated by fresh-water deposits and unconformaties in what is now from necessity designated by a single general term.

The fascinating story of deep erosion, of subsequent lava flows of vast extent, and of renewed outpourings of molten rock, followed by another long period during which streams renewed their work of denudation and canyon cutting, to be read in the landscape spread at the feet of an observer standing on Powell Butte, is not the sole attraction of that commanding station. Beyond the broad valley of the Deschutes rise the wonderfully grand Cascade Mountains, in part at least composed of rocks of the same nature as the Columbia River lava, and in a general summary of the history of the region to be classed with it. How far west of the Cascades the outpourings of basaltic rock of Tertiary and later dates extend remains to be discovered. The lava fields and volcanic mountains of the Northwest are probably the most extensive on the earth and demand attention as furnishing one of the most instructive chapters in the geologic history of our planet. One of the startling facts that come to mind in gazing over the seemingly boundless plains and numbering by the score the volcanic mountains in sight is that not less than 150,000 cubic miles of dense rock have there been transferred from deep within the earth and spread out on its surface. The bearing of such an event on the physics of the earth's crust, the condition of its interior, the nature of the forces which cause magmas to rise in volcanic conduits, etc., are some of the now obscure questions which a complete understanding of the lava fields of the Northwest would assist in answering.

As stated above, the region in the west-central part of Crook County, through which Deschutes River flows, is a great lava-covered plain. On traversing the plain in various directions and following the canyons that have been excavated in it, much of interest concerning its history was discovered, an outline of which will assist in explaining certain more special observations to be recorded later.

The valley of the Deschutes, before it was filled so as to produce the broad, generally level surface which is at present its most conspicuous feature, was from 20 to 30 miles wide in the portion west of the Pauline Mountains and Powell Butte, but perhaps had a less width farther north. This large valley, as may be judged from the character of the portions of its bordering slopes now exposed to view, was produced largely by erosion and was at least 800 feet deeper in its central part than the widely extended sheet of basalt forming the surface of the present plain. The material which partly fills the old valley consists largely of water-laid volcanic dust and lapilli, of which sections 700 feet deep are exposed along the lower portion of the canyon of Crooked River and in the adjacent portion of that of Deschutes River. The total depth of this deposit, however, is as yet unknown, as its bottom is not exposed. After the volcanic dust and lapilli, together with minor quantities of sand and clay, was deposited a sheet of basaltic lava, in general about 80 feet thick, was spread out. Possibly two or more sheets of lava were formed at about the same time which are so similar that their recognition is difficult, and they appear to represent but a single outpouring.

After a lava covering was given to the deep deposit of current-bedded volcanic dust, lapilli, sand, etc., Deschutes River and its tributary, Crooked River, displaced from their former courses, flowed across the plain and excavated canyons, which for many miles near their junction were at least 800 feet deep and in general about a mile wide. The nameless stream which flowed northwest from the Great Sandy Desert (see p. 76) also cut deeply into the lava plain and its underlying deposits of loose material, and joined the Deschutes about 14 miles south of the locality where Crooked River now comes in. Following the period of erosion, during which not only the main streams of the region, but also their tributaries, cut deep canyons, came another considerable discharge of basaltic lava, which entered the canyons in the region where Deschutes and Crooked rivers now mingle their waters and filled them to a depth of at least 500 feet. Later still, Deschutes and Crooked rivers reexcavated their canyons in the hard resistant basalt to a depth of over 500 feet without, so far as known, reaching its bottom. There are thus at least five important episodes in the history of the Deschutes plain that are clearly legible in its present topography.

It would greatly facilitate a description of the several events in the history of the Deschutes plain if names could be applied to the beds of tuff and sand and the two lava flows mentioned above, but as such a course would perhaps lead to confusion when the rocks referred to are correlated with those of adjacent areas, and particularly with the formations of the John Day basin, described by John C. Merriam[a] and others, no attempt to give them names or to assign them a definite position in geologic history will at present be attempted. Apparently, however, the thick deposit of lapilli, etc., beneath the older sheet of basalt is of Tertiary age, and the two periods of canyon cutting belong to the time of general erosion recorded by deep excavations in many parts of North America, and named by Joseph LeConte "the Sierran epoch."

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[a] Merriam, J. C., Contribution to the geology of the John Day basin: Bull. Univ. California, Dept. Geology, vol. 2, 1901, pp. 269–314.

PRINEVILLE VALLEY.

GEOGRAPHY AND GEOLOGY.

Prineville, the county seat of Crook County, a town of about 900 inhabitants, is situated on the border of Crooked River, at the head of an alluvial plain about 6 miles long and from 3 to 4 miles wide. This valley, although small, is of importance on account of the aridity of, and general absence of irrigable land in, the region in which it is located, and is an exceptional feature in the geography of Crooked River, which in all other portions of its course flows through a succession of narrow canyons.

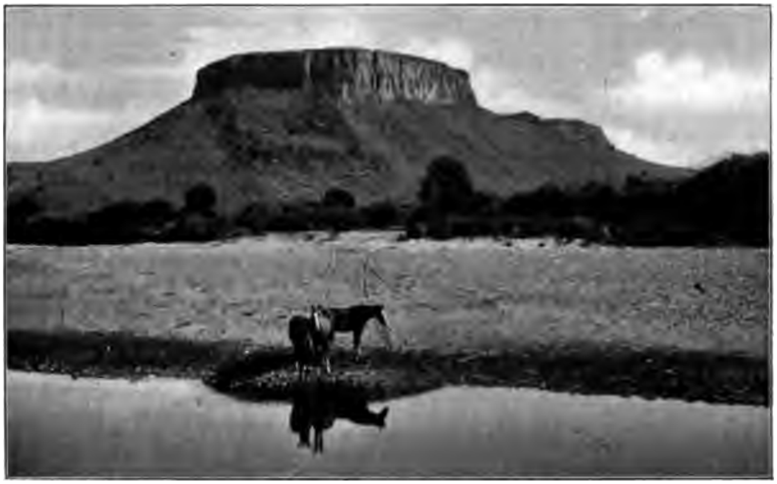
East of Prineville Crooked River flows west through a rugged valley in which outcrops of soft material carrying fossils are reported to occur. About 6 miles before reaching the town it traverses a narrow canyon with vertical walls of basalt about 650 feet high. The basalt is in well-defined layers, with scoriaceous surfaces, of which at least 7 are exposed. The stream has not as yet cut through the pile of basaltic sheets, although a few miles farther up its course the underlying rocks are exposed. This basalt, so far as can be judged from the facts in hand, is to be correlated with the older and more widely extended lava of the Deschutes plain, though present in several sheets instead of a single one. Only one of the sheets, near the top of the section, however, seems to extend west of Prineville.

Less than a mile above Prineville the canyon of Crooked River becomes abruptly wider, and for 6 miles west of that town has a width of 4 or 5 miles, this abrupt increase being due to the presence of soft material beneath the basalt. The canyon is here bounded on the northeast by rocks (probably rhyolitic tuffs) which formed the border of the old Deschutes Valley. Crooked River flowed across the basalt, cutting a canyon near its margin, and, on gaining the soft beds beneath the resistant surface layer, widened its canyon, locally, into a valley. On the west and south side of the river where it turns from a northerly to a westerly course, near Prineville, the surface sheet of basalt is but 30 or 35 feet thick. The base of the sheet is scoriaceous, and embedded in it are fragments of the soft shaly beds on which it rests. The fine sediments immediately beneath the basalt grade downward into soft, coarse sandstone 20 to 30 feet thick, below which are coarse, well-worn gravels and other sedimentary beds reaching, in the face of the cliff, nearly to the river. The canyon wall with its rim rock of basalt is about 250 feet high by aneroid measure.

West of Prineville the wall on the south side of the valley of Crooked River presents a continuation of the condition just de-

A. CANYON OF CROOKED RIVER, 6 MILES BELOW PRINEVILLE, CROOK COUNTY.

From butte shown in *B*; looking west.



B. REMNANT OF BASALT SHEET, 6 MILES WEST OF PRINEVILLE, CROOK COUNTY.

Looking north.

C. PRINEVILLE VALLEY, CROOK COUNTY.

From butte shown in *B*; looking east.

scribed—a rim rock of basalt rising above a talus-covered escarpment that conceals thick water-laid beds. At several localities landslides have occurred and produced interesting variations in the otherwise monotonous line of cliffs with steeply sloping talus spurs at their base. About 6 miles west of Prineville the valley contracts in width and once more becomes a narrow canyon with nearly vertical walls, in which the edges of 6 sheets of horizontally bedded basalt are well exposed. The presence of several sheets of basalt at this locality and in a similar section exposed in the walls of Crooked River Canyon above Prineville, while between the two localities but one sheet is present, is readily explained by the fact that the surface on which the lava while yet molten was spread out was trenched by canyons or valleys. The earlier lava flows entered the depression, which, as successive eruptions took place, became completely filled, while the later sheets were spread widely over the former depressions and the intervening uplands or plateaus. Crooked River has since excavated a new canyon, which in places cuts across the lava sheets occupying its previous valley. Where the channel was cut through a pile of lava sheets its course is through a narrow canyon, and where only one, or but a few, thin lava sheets were present, resting on a thick formation of volcanic lapilli, etc., a wide excavation like the one in which Prineville is located was produced.

In Prineville Valley some interesting modern changes in the work of the river are recorded by gravel terraces, one of which has a surface elevation of 60 feet above the present stream channel. All along the course of the river for several miles below the town the stream meanders in sweeping curves through the alluvial bottom lands and affords fine illustrations of the behavior of an aggrading stream.

The isolated table with a cap of columnar basalt, shown on Pl. IX, *B*, stands on the north side of Crooked River about 6 miles west of Prineville, near where the valley changes to a canyon. This remnant, spared by erosion, is by aneroid measure about 250 feet high and is instructive not only on account of its striking topographic form, but because at the base of the basalt there is evidence that the lava of which it is composed, while yet molten, entered water or at least flowed over a wet surface. The base of the sheet for a thickness of from 3 to 7 feet is open textured, or "shredded," and rough, and has masses of the underlying shale involved in it for a distance of from a few inches to fully 3 feet above the general plane of contact.[a]

WATER RESOURCES.

Surface waters.—From the summit of the erosion remnant just referred to a fine view is obtainable of the broad, fruitful valley to the east, in which the spires of Prineville, when illuminated by an evening sun, gleam brightly in the middle distance. Bordering the yellow-fringed stream on either side are level fields seemingly well located for irrigation, which in the aggregate have an area of perhaps 8 to 10 square miles. This alluvial plain is far too large to be watered by the summer flow of the stream which meanders through it, even when aided by the few small brooks which have their source in springs in the deeper gulches and enter the valley from the hill on its northern border.

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[a] For characteristics of lavas that flowed into water, see Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902, pp. 113–117.

As Prineville will no doubt continue to be a thriving town, and as the adjacent valley contains one of the finest areas of agricultural land in central Oregon, every effort should be made to bring it under cultivation. The first step in this direction is obviously to store the winter run-off of Crooked River and of each of its tributaries that enters the valley. The conditions seem to favor such a plan, but only detailed surveys can be relied upon to show what can be accomplished. One of the difficulties to be met with is the great annual fluctuation in the volume of Crooked River. At times when the snow melts on the mountains to the east, the river rises fully 25 feet above its summer stages, and destructive floods occur. Prineville is within reach of such floods and in danger of a great disaster. In the future growth of the town this should be borne in mind, and safer ground chosen on which to build. Another matter which demands attention is the pollution of the river. Refuse of all sorts is now dumped into the stream or left on its immediate banks, and its water, especially during the low summer stages, is seriously contaminated.

Wells.—Prineville is supplied with water by the Prineville Light and Water Company from a group of 23 " driven " wells, which were put down in 1899 in the eastern portion of the town within a radius of about 100 feet. The deepest well goes down 280 feet; the pipes used are 3 inches in diameter; the water, which is slightly alkaline, is raised by a steam pump, discharging about 300 gallons per minute. The water is stored in a reservoir and distributed through pipes in the usual manner. The material passed through in driving the wells is reported to be as follows:

Section of well at Prineville, Crook County, Oreg.

	Feet.
Soil	5
Gravel, coarse	20
White clay	1
Quicksand, fine	2
Gravel	3 to 4
White clay	2
Quicksand (volcanic dust?)	210

Water was reached at a depth of about 32 feet, but the supply continued to increase until a depth of 60 feet was reached. The main supply comes from the so-called quicksand, probably volcanic dust, found beneath the layer of white clay 32 to 34 feet below the surface. The fine sand, or volcanic dust, is excluded from the pipe by means of wire gauze. The water at first rose 3 to 4 feet above the surface level of the adjacent creek. Its temperature is 54° F.

The rise of the water in the well just described is evidence of artesian pressure and favors the hope that flowing wells can be obtained in the same or adjacent areas. As the wells terminate in the water-bearing stratum, they do not furnish a complete test of the artesian conditions. The formation penetrated is widely extended, and in the walls of the canyons of Crooked and Deschutes rivers near their junction is over 800 feet thick, but the lower limit is unknown. While the thickness of the porous beds in these canyons does not prove that the portion of the deposit beneath Prineville is equally thick, yet it is at least a suggestion that the present wells might be continued much deeper with the hope of obtaining an additional water supply.

The geologic conditions shown by the wells at Prineville and by the sections exposed in the canyons of Crooked and Deschutes rivers, together with such evidence as is available concerning the topography of the region, all favor the hope that artesian water can be had in Prineville Valley.

The presence of a definite artesian basin is not suggested by the known conditions, however, but rather by the possibility that an "artesian slope,"[a] or wedge-shaped beds of previous material inclosed in impervious material, may be present. While no prediction worthy of consideration can be made that flowing water will be obtained in the valley if wells are drilled, the conditions are such as to warrant making a thorough test in that connection at any point on the alluvial bottom lands from Prineville to Forest.

For the benefit of the people interested in the development of Prineville Valley I venture to suggest the propriety of their combining in an enterprise having for its aim the making of a thorough test of the possible artesian conditions beneath the valley. A number of the owners of land in the valley might well contribute to the cost of putting down a well, the expense to be shared by all if failure resulted, and the owner of the land on which the well is drilled to meet the entire cost if flowing water should be obtained. One flowing well would be evidence that others in various parts of the valley would probably be successful. The water-bearing formation, however, is composed of many variable layers, and so far as can now be judged no one of them may be widely extended.

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[a] Russell, I. C., Geology and water resources of the Snake River plains of Idaho: Bull. U. S. Geol. Survey No. 199, 1902.

The proposed test well should be put down on the north side of Crooked River, in the vicinity of the medial line of the valley, and continued until hard rock is reached. The well should be drilled under the direction of a competent hydraulic engineer who has had extensive experience in that line of work, and the pressure in each water-bearing layer accurately tested. The nature of the records that it is desirable should be kept while drilling such a well has been indicated in a previous report.[a]

CANYONS OF CROOKED RIVER BELOW PRINEVILLE VALLEY.

About 6 miles west of Prineville, as already stated, the valley excavated by Crooked River contracts in width and becomes a canyon, but for a distance of about 6 miles farther, or to the vicinity of the former post-office known as Forest (where there is now a store and where, as may reasonably be expected, a village will in time be built), there is alluvial land on the borders of the river, now occupied by several valuable ranches. The portion of the canyon above Forest is in reality a continuation of Prineville Valley and shares with it the probability of future agricultural development. Below Forest all the way to the Deschutes, a distance of over 30 miles, Crooked River flows through a narrow canyon with essentially, and often actually, vertical walls, and there is no alluvial land in its bottom. Throughout this portion of the river there is but one place where a team and wagon or even a pack train can be taken across it, namely, at Trail Crossing, about 18 miles below Prineville and 7 miles below Forest. Toward this locality Indian trails formerly converged on each side of the river; later, frontiersmen, with their saddle ponies and pack horses, sought the same breaks in the canyon walls; and within the past few years a road has been graded on the declivities of the opposite-facing precipices and a good bridge thrown across the river. Trail Crossing is thus an instructive locality in reference to the control exerted by geographic conditions on the affairs of men. The canyon, too, is of great geologic interest, and, on account of its wildness and picturesqueness, will no doubt in the future attract to its secluded depths many curious travelers.

The portion of the canyon of Crooked River under consideration may be divided into two portions, which are strikingly different, and for convenience may with propriety be given independent names. From near Forest to Trail Crossing, Crooked River has excavated its canyon along the border of the vast lava fields extending from the brink of its left wall westward, and on the right has eroded the base

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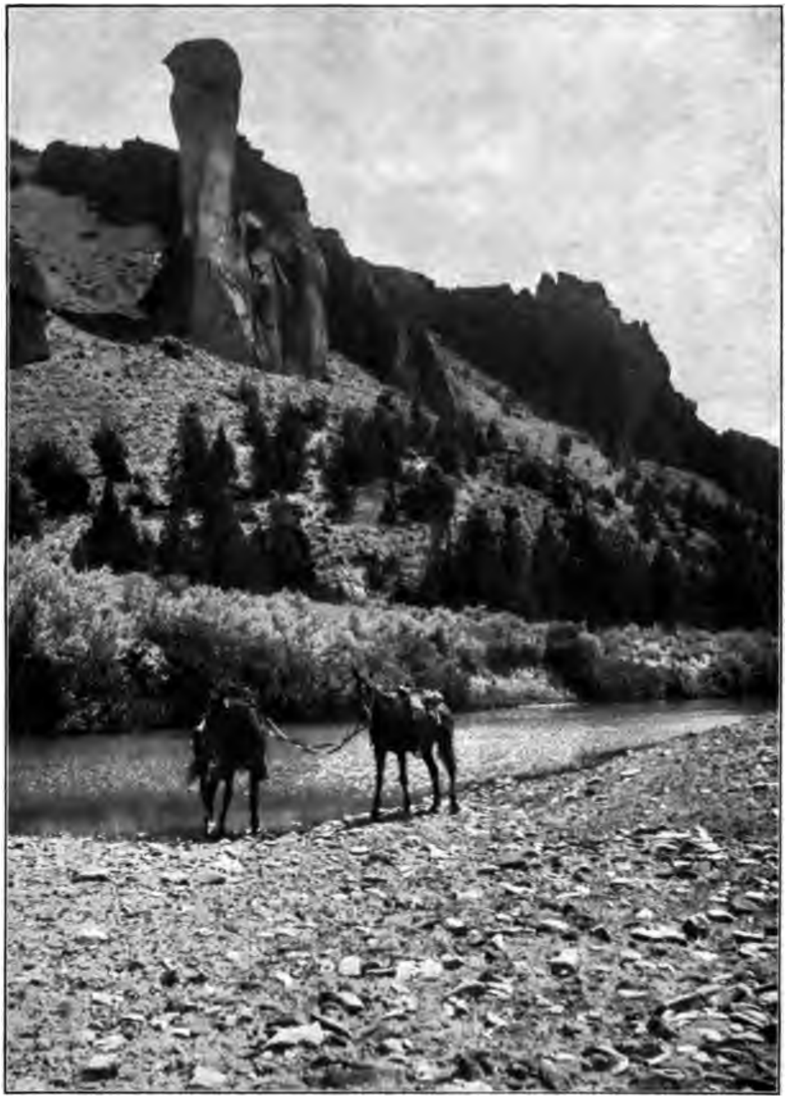
[a] Russell, I. C., Preliminary report on artesian basins in southwestern Idaho and southeastern Oregon: Water-Sup. and Irr. Paper No. 78, U. S. Geol. Survey, 1903.



EROSION COLUMN ON NORTH WALL OF MONUMENT CANYON, CROOKED RIVER, CROOK COUNTY.

of a rugged mountain composed of light-colored acid tuffs cut by a great basic dike. The tuffs, under the destructive action of wind and rain, have been sculptured into many remarkable monumental forms, one of which is shown on Pl. X. On account of these unique monuments of atmospheric erosion the portion of the canyon to which they add picturesqueness may well be termed "Monument Canyon." Below Trail Crossing the canyon of Crooked River becomes still narrower and assumes the characteristics of what are significantly termed "box canyons." In its bottom, about midway between Trail Crossing and the mouth of the river, a superb flow of clear, cool water, known as Opal Spring, gushes out of the rocks. To the portion of the canyon to which this spring adds an especially attractive feature, giving in summer new life to the exhausted river, the name Opal Canyon may fittingly be applied.

MONUMENT CANYON.

The left, or southern, wall of Monument Canyon, approximately 250 feet high, is surmounted by a rim rock of basalt about 40 feet thick, beneath which are soft, unconsolidated, stratified deposits, consisting mostly of tuff. The contact of the basalt with the formation on which it rests is irregular and even rugged, indicating that the lava, while molten, advanced over a wet surface. Along the plane of contact the tuff beds are changed from their usually gray or yellowish colors to red, on account of the oxidation of the iron they contain. The sheet of basalt exposed in section in the canyon wall extends southward from the brink of the canyon for about a mile, and has an uneven surface in part smoothed over by wind-deposited dust, which forms a rich soil. Its southern margin skirts the base of an irregular escarpment of basalt, about 100 feet high, from the crest of which a plain of basalt extends south and west for many miles. This escarpment is the rim rock of an old canyon cut by Crooked River, which was later invaded by a lava stream, or rather inundation of molten rock, which gave it its present rough surface. Subsequent to this event the river excavated the present and deeper canyon, on the northern slope of which the remarkable erosion columns from which it derives its name are situated.

The north wall of Monument Canyon rises precipitously several hundred feet higher than the nearly level-crested cliff bordering it on the south, and presents striking contrasts to it in nearly every feature. The mountain-like elevation on the north is composed mainly of light-colored, mostly yellowish, tuffs in well-defined beds, which in general dip northeast at angles of 40° to 50°. The beds are of unequal hardness, some being resistant to the destructive action of wind and rain and standing out beyond their neighbors as sharp serrated ridges, along which are numerous pinnacles and spines. Cutting the consolidated and steeply inclined tuff beds is an immense dike of dark basic rock, probably basalt, which has a width of about 1,000 feet and trends northeast and southwest. To the northeast the dike can be traced for a mile or more, and in its present weathered condition forms rounded hills and domes, conspicuous on account of their rich brown colors.

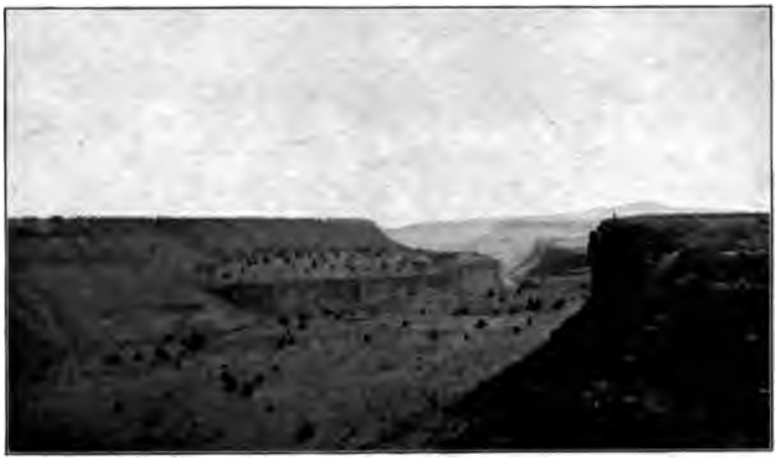
In Monument Canyon a wonderfully interesting page of the earth's history is laid open, but its full meaning can only be interpreted after more careful investigation than my necessarily hurried visit permitted. The lesson it teaches pertains to the region to the north, and particularly to the history of Gray Butte and the country about Culver and Haystack, but must be left for future study.

OPAL CANYON.

Crooked River at Trail Crossing, at the time of my visit early in August, had shrunk to a brook of tepid, muddy, and unwholesome water, across which one could step dry-shod from stone to stone. Its volume, by estimate, was not more than 2 cubic feet per second. The high-water marks along the sides of the canyon, however, were about 25 feet above its nearly dry floor. On descending into the canyon about 12 miles lower down its course I was surprised to find a swift-flowing, clear stream of cool, delicious water, by estimate 100 feet wide and 3 feet deep, with a volume of not less than 300 cubic feet per second. This remarkable renewal or resuscitation of a stream in an arid land is due to the inflow of Opal and other similar springs. The probability that this subterranean water supply comes from far up the course of Deschutes River, where its banks are of open-textured basalt, will be considered later in describing the influence that a recent lava flow from Lava Butte exerts on the volume of the Deschutes (pp. 116–117).

DOUBLE CANYONS.

The most conspicuous fact in the geography of Crooked River Canyon is that in places it consists of two canyons, an outer and an inner one. On crossing the adjacent basaltic plain below Opal Spring and gaining the brink of the outer canyon, one finds that it is margined on each side by a vertical escarpment or rim rock of basalt, in general from 80 to 100 feet thick, beneath which there are soft, incoherent beds, the outcrops of which in the canyon's walls are in most places concealed beneath talus slopes or débris aprons. At a level of 250 feet below the crest of the outer canyon there is a generally flat floor with a surface rough except where wind-deposited dust has accumulated or sand and gravel from its bordering escarpment has been washed out upon it. Cut in this is the inner canyon, which for a distance of from 3 to 4 miles below Opal Spring is 550 feet deep (Pl. XI, *A*, *B*). The outer canyon is here in general form 1 to 1½ miles



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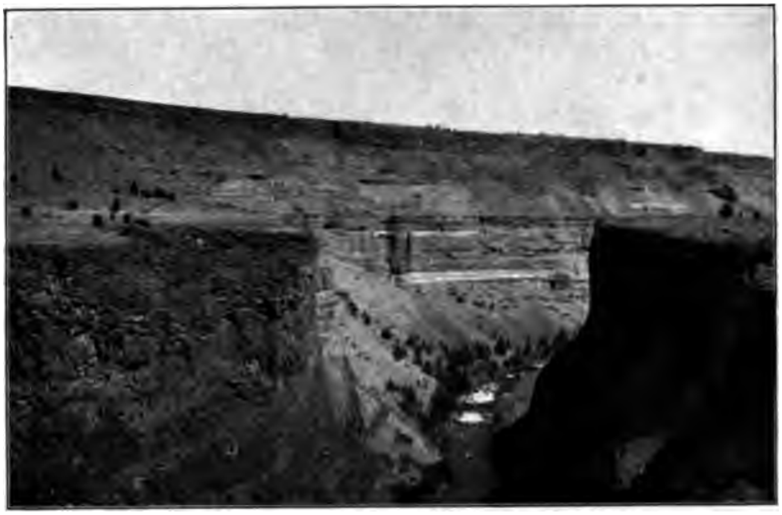
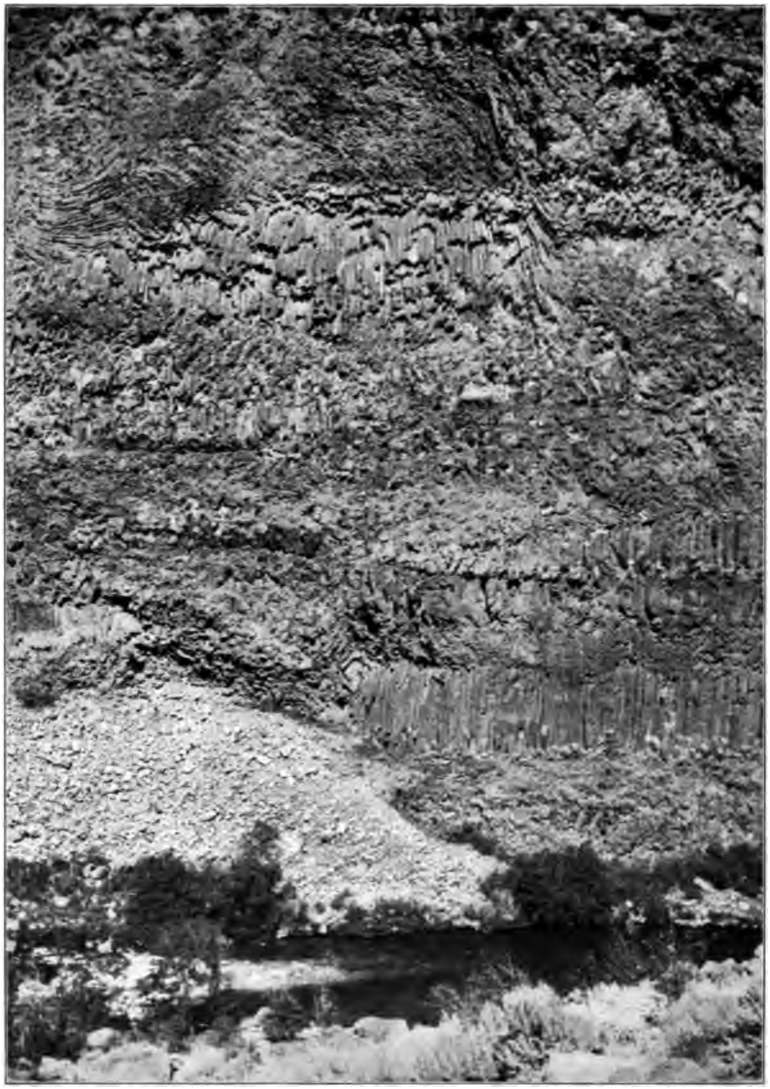


B

VIEWS IN OPAL CANYON, CROOKED RIVER, CROOK COUNTY.

A, Looking north; *B*, showing basalt of inner canyon in contact with stratified beds of outer canyon.



JOINTED BASALT IN WALL OF INNER CANYON, NEAR OPAL SPRING, CROOKED RIVER, CROOK COUNTY.

wide, but has a greater width farther north, where it unites with the similar canyon occupied by Deschutes River. The inner canyon is irregular both in direction and in width. In places it is margined on each side by the floor of the outer canyon and in other places the two canyons have a common wall on one side. The sides of the inner canyon, where it is situated medially in the floor of the outer canyon, are of compact basalt, without well-defined or continuous bedding, but with irregular columns from base to summit (Pl. XII). Where the walls of the two canyons coincide a thickness of 650 feet of irregularly bedded clay, sand, gravel, and volcanic dust and lapilla is exposed, above which is a rim rock from 80 to 100 feet thick of the basalt which forms the surface of the greater part of the Deschutes plain. Where the inner canyon has a wall of basalt on each side it is seldom more than 500 or 600 feet across, but its width increases to 800 or 1,000 feet where the two canyons have one wall in common.

The conditions just described occur again, with nearly the same details, in the canyon of Deschutes River for a distance of about 8 miles upstream from where Crooked River joins it. How far below or north of the junction of the two rivers the inner canyon extends on the Deschutes is unknown to the writer.

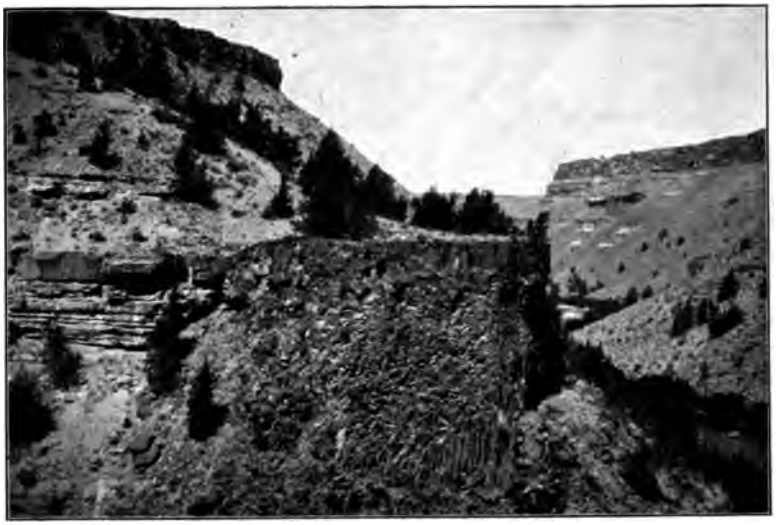
The history recorded in the facts described above is in brief as follows: After the broad ancient valley of the Deschutes had been filled to a depth in excess of 700 feet with loose stream-deposited débris, consisting mostly of black volcanic sand and gravel, and this material covered by the widely extended sheet of basalt now forming the surface of the major portion of the Deschutes plain, the rivers displaced from their former courses flowed across the young lava plain and excavated canyons in it, which, in the case of Deschutes and Crooked rivers, are a mile wide and over 800 feet deep. Next came a flow of molten basaltic rock, which entered the canyons and filled them to a depth of over 550 feet for many miles. Subsequently the same streams, again displaced but still confined to their former but deeply filled canyons, resumed their work of erosion and cut, in solid basalt, the inner canyon described above. In the portion of the canyon examined the task of cutting through this layer is as yet incomplete, and the rivers flow swiftly over solid, compact basalt.

This is one of the most remarkable instances known of a river struggling, as it were, to maintain its right of way against the opposition offered by stupendous showers or downpourings of volcanic dust and lapilli and by vast outflows of lava which hardened into dense, resistant rock. The time occupied in the excavation of the outer canyons was probably not great, as the material in which these were excavated, with the exception of the covering sheet, was loose and incoherent, but the inner canyons, in places, and for distances in several instances of at least 2 or 3 miles, were cut in hard, compact basalt, and their erosion to a depth of 550 feet must have required many thousands of years. It is worthy of note, however, that the conditions along the courses of both Deschutes and Crooked rivers, in the region under consideration, are usually favorable for rapid erosion. The rivers are swift, and the abundance of loose, coarse sand and gravel discharged into them where they wash the borders of the older or outer canyons furnishes as large a supply of abrasive material as the water can transport. In the case of Crooked River these favorable conditions are still more enhanced by the spring freshets that occur, during which the river becomes a raging torrent. These favorable conditions for rapid mechanical erosion are offset, however, by the hardness of the rocks over which the rivers flow, and the task of deepening the channels has progressed but slowly.

Pl. XI, *A*, shows both the outer and inner canyon of Crooked River about 3 miles north of Opal Spring. The view is northward, and the hill on the distant table-land is a low steptoe, about 5 miles northwest of the village of Haystack. To the left in the picture can be seen the junction of the basalt, in which the inner canyon has been excavated, with the stratified volcanic gravel, etc., of the outer canyon. Pl. XI, *B*, shows the wall of the outer canyon as seen from the brink of the inner canyon. Details in the wall of the inner canyon, and especially the irregular jointing of the basalt, are shown on Pl. XII. Contrasted with the vertically jointed basalt of the inner canyon is the horizontal although irregular bedding of the material forming the walls of the outer canyon below their rim rock of basalt, in which white layers of volcanic dust are conspicuous, as may be seen on Pl. XI, *B*. Beds of diatomaceous earth are perhaps also present. Pl. XIII, *A*, shows a remnant of the wall of the inner canyon of the Deschutes abutting against the escarpment of the outer canyon about 8 miles upstream from the mouth of Crooked River. Pl. XIII, *B*, illustrates the topography of the canyon of Deschutes River upstream from where it was invaded by a flow of basalt.

DESCHUTES SAND.

The material forming the walls of the outer canyon of Deschutes and Crooked rivers demands careful study with reference not only to its composition and the evidence it contains respecting the conditions under which it was deposited, but in order to learn how far it meets the conditions favoring the retention of water under pressure. This same formation, it will be remembered, extends eastward and underlies Prineville Valley, where artesian water will probably be discovered. It also underlies the sheet of basalt exposed here and there beneath the rich, wind-deposited soils of a large section of the



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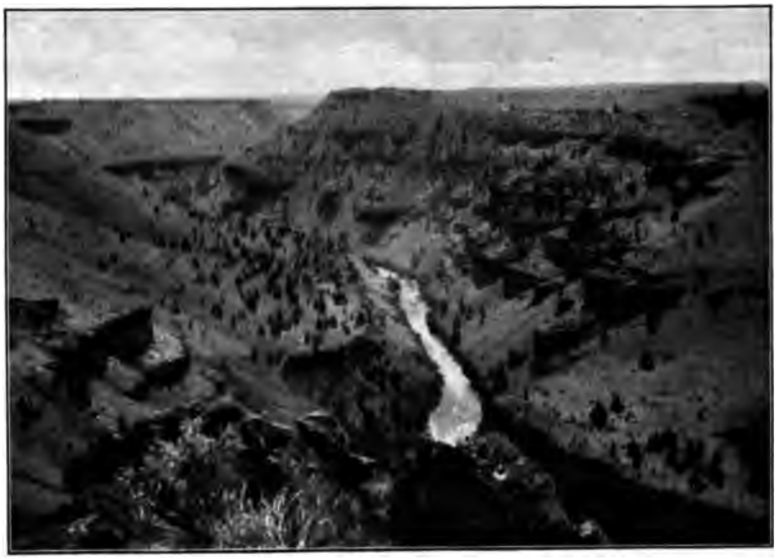

B

VIEWS IN CANYON OF DESCHUTES RIVER, NEAR MOUTH OF CROOKED RIVER.

A, Showing remnant of basalt in canyon excavated in stratified deposits; *B*, looking south.

Haystack country, to the north and east of Opal Canyon. Sufficient attention has not as yet been given to the formation in question to enable a description of it to be put on record, but such notes as are available show that it was waterlaid, probably by widely expanded and fully loaded or overloaded streams, which divided and reunited after the manner of " laced " streams. The nature of streams of this class is indicated by the well-known example of Platte River, Nebraska, which flows over its broad, sandy bed in many locally separate but constantly uniting and again subdividing channels. The material forming the " Deschutes sand," as the formation will perhaps be termed when its history is more fully studied, consists largely of black basic and frequently scoriaceous grains and kernels of volcanic rock, forming a coarse sand, mingled with which are lesser quantities of quartz grains. Although the stratification is distinct and the beds thinly laminated, the individual layers can not usually be traced for more than a few hundred yards. The deposit throughout is frequently cross-bedded; that is, contains evidence of having been deposited by strong currents. Some of the beds are composed of well-worn gravel, the pebbles at times being 6 to 8 inches in diameter. Clay-like beds, which would evidently serve the rôle of retaining layer in an artesian basin, are present, but, so far as seen, are local accumulations rather than widely extended strata. The most conspicuous layers, of which 10 or more can sometimes be counted, are composed of white volcanic dust. A bed of white diatomaceous earth, identical in appearance with the volcanic dust referred to, was found at the lower bridge across the Deschutes, about 20 miles south of the mouth of Crooked River, and other similar beds may be present in the adjacent region. This diatomaceous earth is composed of the beautiful siliceous cases or frustules of certain minute one-celled algæ, and resembles the finer grades of white volcanic dust so closely that a microscope is required to reveal the difference to the eye.

The formation referred to above as the Deschute sands is exposed in the canyon wall of the river after which it is named for at least 25 miles upstream from the mouth of Crooked River, and is probably present for a long distance below that locality. It is also exposed, as has been stated, at many localities in the canyon walls of Crooked River from Prineville west to the Deschutes, and, no doubt, underlies several hundred square miles of the Deschutes plain.

THE HAYSTACK COUNTRY.

SOIL AND SETTLEMENT.

In the north-central portion of Crook County, north and east of Opal Canyon, and east of the Deschutes below the mouth of Crooked River, there is an area embracing at least 8 or 10 townships, most of which is an undulating plain covered with a fine rich soil. In a state of nature this great tract of open country was a prairie of bunch grass roamed over by antelope and deer, and owing to the scarcity of water, which prohibits summer pasturing, much of the land is still well clothed with native grasses. The soil is fine in texture, and evidently owes its origin principally to the deposition of wind-borne dust. In the nature of its soil, the luxuriance of the native grasses, and also in the fact that "dry farming" is successfully carried on, this region resembles the Palouse country of eastern Washington, famous for its highly productive wheat fields. In each of these extensive regions favorable yields of grain can be grown without irrigation, although the mean annual precipitation is too small to permit successful agriculture unless some exceptionally favorable soil condition is present. The determinative condition is the retentive character of the fine, flour-like soil, which permits it to absorb and retain tenaciously all of the water that falls upon it.

The region about Culver, Haystack, Haycreek, etc., or the "Haystack country," as it is familiarly termed on account of the abundant crops of hay obtained in certain favored tracts where water is available for irrigation, is becoming occupied by farms with wonderful rapidity. During the past three or four years the rush of ranchers to this new farming land—new in the sense that the discovery that cereals and even maize can be raised on it is but recent—can be compared to the rush of fortune seekers to a new gold field. The broad, grassy plain, which a few years ago was tenantless, is now dotted with settlers' cabins, the freshly sawed boards of which still gleam yellow in the intense sunlight. This region of dry farming may also be said to be a country of dry housekeeping, since no water is available for domestic use within a distance of several miles of the majority of the recently built houses. In the case of about 300 homes, situated to the west of Culver and south of Haystack, water for domestic use is transported in wagon tanks for distances ranging from 5 to 10 miles. The one most essential thing on which the future prosperity of this otherwise favored region is dependent is the procuring of a water supply adequate at least for household uses and for the maintenance of stock in sufficient numbers to carry on grain and hay ranches.

WATER SUPPLY.

This interesting and economically highly promising region was barely entered during the reconnaissance and no more can be said in reference to its water resources than that it has possibilities that demand careful consideration from hydraulic engineers. As to the question of obtaining artesian water, but little information is available, but that little is suggestive and warrants further study. On the east the Haystack country is bordered by uplands having a mature topography such as hills long exposed to the denuding agencies of the air and of rain and streams commonly present. These uplands were a part of the eastern border of Deschutes Valley before it became deeply filled with volcanic dust, sand, gravel, etc., and flooded with lava. Its rocks are composed, so far as known, and judging from topographic forms seen at a distance, probably to a great extent of compact tuffs, in beds which dip westward and pass beneath the Deschutes plains. The hills when seen in profile from the south present long slopes on the western sides and steep, rocky escarpments facing east. In a general way this structure is favorable to the hope of obtaining artesian water where the rocks referred to underlie the plain to the west, but the nature of the rocks, whether containing alternating porous and impervious beds, etc., is unknown. To the west of the ancient uplands and terminating against them are the lava flows and underlying gravels, etc., of Deschutes Valley. In the open-textured deposits beneath the surface sheet of basalt, as in Prineville Valley, there is a possibility that water under pressure may exist, but an answer to this question can only be had by drilling test wells.

Although nothing definite can at present be said in reference to the probability of obtaining flowing water in the Haystack country, it seems safe to predict that wells drilled through the basalt which occurs beneath the soil of the plain to the west of Culver and Haystack will at least furnish water which can be raised by means of pumps. The localities most favorable for such tests are on the broad plain at as great a distance as practicable from hills. This restriction is made because in at least one locality about 10 miles west of Haystack the older rocks, probably tuffs, which underlie the more recent gravels, basalt, etc., that now give a level floor to Deschutes Valley rise to the surface and form a low steptoe, or isolated hill, in the lava plain. A well put down here would probably pass through about 100 feet of compact basalt, exceedingly hard to penetrate, and enter the thick deposit of gravel, tuff, volcanic dust, etc., which occurs beneath it. As already stated, however, this sedimentary formation had an uneven surface and was in places deeply trenched previous to being covered with the basalt that now rests upon it, so that an even greater thickness of basalt than that mentioned might be encountered. In this connection it may be suggested that if more than 125 feet of basalt should be discovered in drilling a test well the abandonment of the undertaking and another attempt a mile or so away would be justified.

As stated above, my journey took me to the margin of the Haystack country, and although the desirability of making a study of its geology, at least so far as the facts bearing on the possibility of a subterranean water supply are concerned, was fully recognized, the extent of country to be examined was seen to be so great that the hope of traversing it in the time available had to be abandoned. One conclusion reached during my hasty visit which may be welcome to the residents of the region is that the conditions favoring agriculture are there so great that unusual efforts are justified in attempting to supply the demand for water.

I have been informed by Mr. A. M. Drake, president of the Pilot Butte Development Company, that detailed surveys made under his direction have shown that water taken from Deschutes River at Benham Falls can be conducted across the broad lava plain lying between Powell and Pilot buttes and across Opal Canyon to the rich lands lying west of Culver and Haystack. This is a part of an extensive and apparently well-matured plan for the irrigation of a vast extent of now unproductive land in the west-central part of Crook County, concerning which I am not in a position to do more than make mention at this time.

VOLCANIC CONES.

BUTTES.

Character and age.—On the east side of the Cascade Mountains in Oregon, and in general from 15 to 30 miles from their crest, are a number of isolated conical buttes, which from their shapes and what is known of the general geology of the region, as well as the somewhat detailed information concerning a few of them which is in hand, may be safely classed as volcanic peaks. They evidently present a wide range in age and considerable variations in the nature of the rocks of which they are composed.

The buttes referred to are associated with the Cascade Mountains, and in a comprehensive study of the geology of that range should evidently be considered as adjuncts to it. On the other hand, their isolation in many instances and their evident independence of all neighboring elevations make them features of the broad lowlands of the central part of the State.

In the case of mountains left by the erosion of upraised portions of the earth's crust, and also in examples of deeply dissected volcanic mountains, isolated remnants of the formerly more extensive uplands about their borders are frequently left and are conveniently designated foothills. But in the case of the Cascade Mountains in Oregon a magnificent example of built-up mountains is furnished, in which the constructional agency was volcanic energy, and the flanking elevations or foothills, instead of being remnants left by erosion, are of the same character as the main range. These secondary volcanic piles may be roughly classified as ancient or modern. In general, the older series of volcanic cones and associated lava fields are composed of andesite and related lavas, and the younger series for the most part of basaltic rocks. This generalization, however, is not strictly true, and, perhaps, not well founded, since some of the most recent of the volcanoes in question discharged acid lavas of the nature of andesite.

These volcanoes may safely be concluded to range in geologic age from the earlier portion of the Tertiary period to recent centuries. They number several hundred, and extend geographically across the entire width of Oregon and no doubt far into the region to the north and south of the State. Although several of them were visited, only an indefinite and unsatisfactory beginning of their study could be made.

The most prominent examples of the older of these secondary volcanic piles in the portion of Crook County traversed are Pilot and Black buttes. These were visited and something of their histories ascertained.

Pilot Butte.—To travelers on the broad lava plain west of Powell Butte a conspicuous landmark is furnished by an isolated conical elevation, long known as Pilot Butte, which is situated near the recently established town of Farewell Bend, on the east bank of the Deschutes. This butte has a height of about 500[a] feet above the adjacent plain, and has steep sides and a moderately sharp summit. It is an ancient volcanic cone composed of basalt, containing conspicuous crystals of hypersthene, which occurs mostly in the form of angular fragments of scoriaceous rock, but with an exposure of reddish scoriaceous lava about its summit. No vestige remains of the crater which probably once existed at the top of the cone, and its sides have lost the graceful concave curves that usually characterize such piles when fresh. Basaltic lava of the same character as that forming the lapilli and scoriæ of the cone is present on the northern side of its base, and may be traced for about half a mile to where it disappears beneath more recent basalt. The old lava exposed is probably a portion of a stream which emerged from the base of the butte, but evidence as to the details in its history is wanting.

Pilot Butte is now entirely surrounded by a nearly level sheet of recent basalt and rises as a steptoe above it. A mile west of the butte the Deschutes has cut a canyon to a depth of perhaps 100 feet in the irregular and fresh-appearing basalt which covers the plain. The butte stands at the margin of the vast pine forest, which extends west beyond the crest of the Cascade Mountains and is itself sparsely tree covered. To the east scattered groves of juniper reach far out on the broad lava plain. The view from the summit of the butte is unusually fine, commanding, as it does, the dark Cascade Mountains with their snowy peaks.

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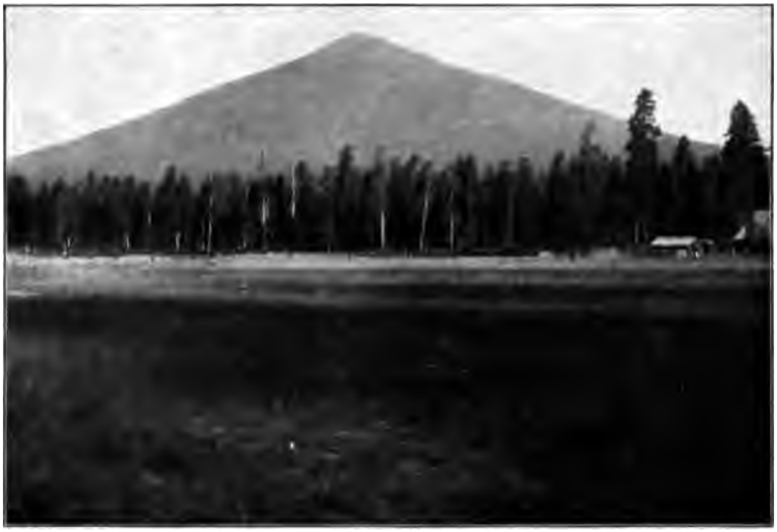
[a] The height of Pilot Butte, as determined by L. D. Wiest, C. E., of the Pilot Butte Development Company, is 4,152 feet above sea level, and the elevation of the Deschutes at Farewell Bend is 3,622 feet, the possible error in each case being ± 40 feet on account of uncertainty of the datum plane.

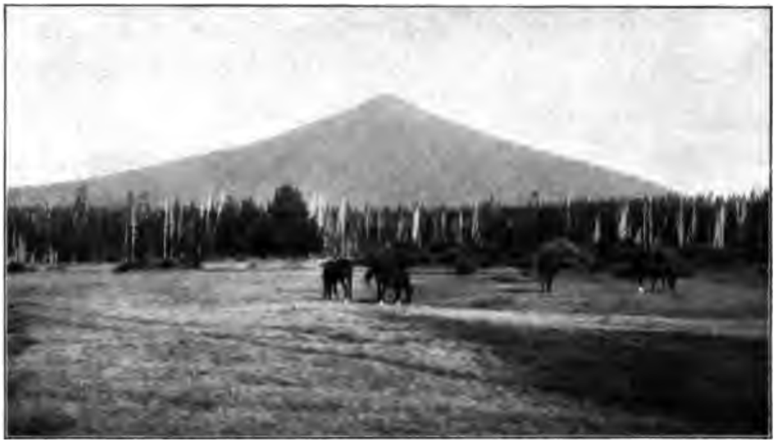
Black Butte.—Rising from the magnificent pine forest which clothes the eastern slope of the Cascades in Crook County and extends far out on the adjacent plain is an isolated peak that is visible for scores of miles throughout the sagebrush country to the east. This peak, known as Black Butte, is situated about 8 miles northwest of the town of Sisters and approximately 15 miles east of the crest line of the Cascade Mountains. The butte is by aneroid measure about 2,500 feet high, is conical, and has a nearly circular base, the symmetry of which, however, has been somewhat marred by erosion. The sides of the butte have lost their original graceful concave curves of construction and are nearly straight when seen in profile, as may be judged from the view shown in Pl. XIV, *A*. The western side has an inclination of 20 to 21 degrees, while the eastern forms an angle with a horizontal plane of about 15 degrees. In each instance the inclination increases somewhat near the summit, the northern slope being the most precipitous and the most modified by erosion. The rock is hypersthene-basalt of about the same character as that composing Pilot Butte, and, so far as surface exposures are concerned, is mostly in the form of angular fragments, imitating a coarse lapilli, but at the top there occur outcrops of massive rock in conspicuous ledges. These summit crags of compact porphyritic rock are evidently the upper portion of a plug or core of lava that cooled slowly and hardened in the conduit of the volcanic pile and was subsequently exposed by erosion. No evidence of a former crater remains. The butte is forest covered, and from its summit a splendid view of the Cascade Mountains and of the arid country to the east as far as the Blue Mountains in northeastern Oregon may be obtained.

From the northeast base of Black Butte a canyon several hundred feet deep leads northeast and is occupied by Metolis Creek, which has its source in a magnificent spring of clear, cold water and forms a rushing brook 40 feet wide with an average depth of 2 feet.

Other buttes.—Besides Pilot and Black buttes there are several similar elevations in the western part of Crook County, which were not visited, but appear to be of the same nature when seen from a distance. Other similar isolated mountains, adjacent to the Cascades and belonging to the same general series of volcanic eruptions that built the mountain range, occur to the south of Crook County; one of these, Odell Peak, is shown on Pl. XIV, *B*. This is also a conical pile of hypersthene-basalt, now considerably eroded, but preserving something of its original constructional form. As in the case of Black Butte, a crater is absent, and at the summit dense lavas have



A BLACK BUTTE, NEAR SISTERS, CROOK COUNTY.



B. ODELL BUTTE, NEAR ODELL LAKE, KLAMATH COUNTY.

been exposed by erosion. The buttes, as may be judged from the amount of erosion they have suffered, are of ancient date and probably belong to the Tertiary division of geologic history.

MOUNT NEWBERRY.

In the south-central part of Crook County, 40 miles in a direct line east of the crest of the Cascade Mountains, there stands a dark-forested mountain of notable height and widely expanded base, in the deeply eroded summit of which Pauline and East lakes are situated. The mountain is surrounded by many lesser elevations, most of which have still recognizable craters, and is connected on its northeast side by intervening highlands with the Pauline Mountains, as designated on the General Land Office map of Oregon. Reference has already been made to the fact that the large mountain in the eroded summit of which Pauline and East lakes are situated is locally considered part of the Pauline Mountains, and the desirability stated of giving it a separate and individual name. For this purpose none seems more appropriate than that of one of the earlier explorers of Oregon, who did much to make the geography, geology, and botany of the State widely known. I refer to Dr. John Strong Newberry, one of the geologists of the "Pacific Railway Survey," and venture to term the mountain in question Mount Newberry in his honor.

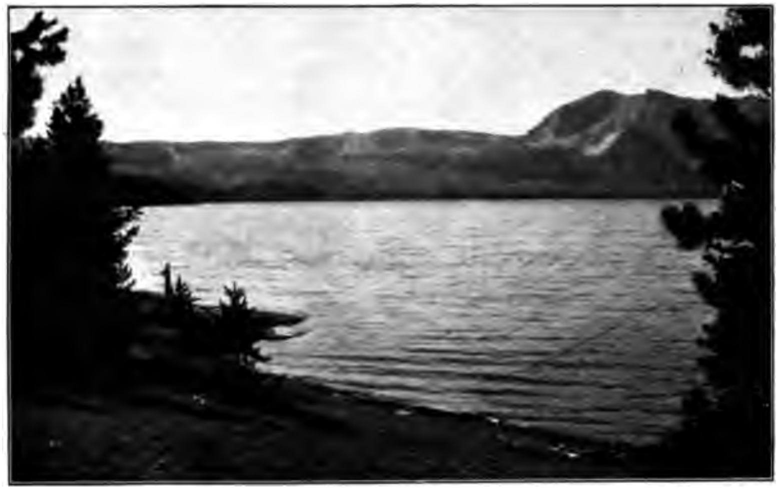
The sharp culminating peak of Mount Newberry, according to measurements made by the United States Geological Survey West of the One Hundredth Meridian (the "Wheeler Survey"), has an elevation of 7,387 feet above the sea. The approximate height of the adjacent portion of the valley of the Deschutes is 4,200 feet, making the visual height of the mountain as seen from the west about 3,000 feet. The mountain is prominent from every point of view from which it can be seen, and has a greater height than that of the adjacent portion of the crest line of the Cascade Mountains. The base of the mountain is widely extended, its diameter being in the neighborhood of 20 or 25 miles, but is indefinite on all sides except the west because of the associated but lesser mountains and the numerous volcanic craters of recent date that surround it.

Historical summary.—The salient facts in the history of Mount Newberry may be briefly stated as follows: It is an andesitic volcanic mountain of probably early Tertiary age, the upper part of which has been removed, and a great amphitheater eroded in the summit of the portion remaining. The amphitheater had an opening on its northwest side, and was occupied by a névé during the Glacial epoch, from which a glacier flowed northward for a distance of at least 3 or 4 and probably more miles. During a stage in the shrinking of the glacier it deposited a large terminal moraine across the opening of the amphitheater through which it flowed, thus forming a dam which confined the water as the glacier melted and finally disappeared. A lake thus originated which discharged across the lowest place in its retaining morainal dam, and cut down an outlet, which has since been deepened in the rocks beneath. Subsequent to the melting of the glacier referred to, volcanic energy within the amphitheater was renewed, and five andesitic volcanoes formed along a north and south belt, which crosses the depression slightly to the east of its center. A lava stream discharged from the most northern of the five craters met the cone built by the next in the series and divided the basin into two parts. To the east of the obstruction lies East Lake, which has no surface outlet, and to the west Pauline Lake, which discharges through the outlet mentioned above and supplies Pauline Creek.

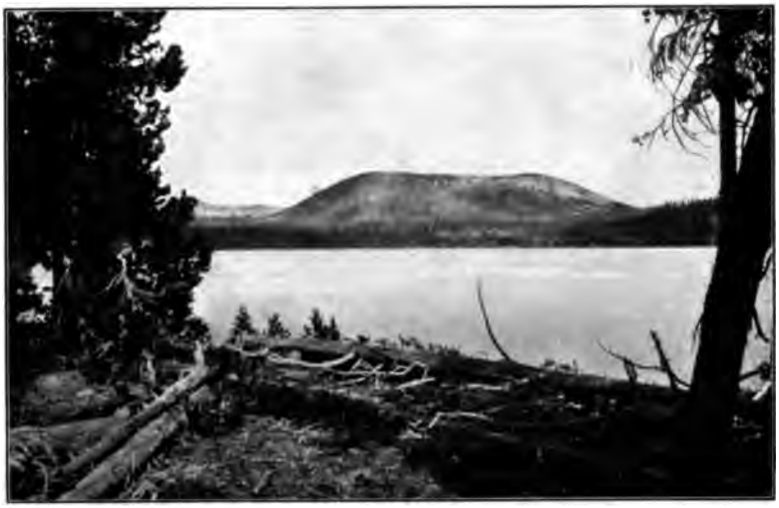
More recent than Mount Newberry, and in part at least of later date than the Glacial epoch, are many basaltic craters, mostly of small size, situated on its outer slopes and scattered irregularly over the adjacent country, particularly to the north and the south.

The northern border of the great amphitheater consists of dark lavas and tuffs, which form rounded domes nearly as high as the present summit of the main peak. These rocks are of later date than those exposed in the southern part of the rim of the amphitheater, but are glaciated, thus showing that they are older than the several volcanic craters of the vicinity which still preserve their constructional forms.

Geology.—The rocks composing the older portion of Mount Newberry and situated to the south of an east and west line passing through the center of Pauline Lake are andesite, and, although no critical study of them has yet been made, it may be provisionally stated that they present a wide range in physical characteristics and include obsidian as well as stony and spherulitic representatives. In each variety there is frequently a well-defined flow structure. These lavas occur in distinct beds, which in several instances—as in the cliffs overlooking Pauline Lake on the south—are from 80 to 100 or more feet thick. From these cliffs, in which the broken edges of the strata are exposed in nearly horizontal bands, the dip is outward from the basin occupied by Pauline Lake, at angles of from 10° to about 15°. The cliffs which rise so prominently on the south side of Pauline Lake and from the north wall of the culminating peak extend about the southeast and east side of the basin as shown in Pl. XV, *A*, and, as judged from distant views, are composed of the same kind of rock, at least as far as the southeast border of the basin in which East Lake is situated is concerned.



A



B

VIEWS IN AMPHITHEATER OF MOUNT NEWBERRY, FROM WEST SHORE OF PAULINE LAKE.

A, Cliffs on southeast side; *B*, crater No. 2.

About the northern portion of the basin the encircling mountains, although precipitous, do not rise in vertical cliffs. The rocks are dark, and in places reveal red and brown colors, in contrast with the gray cliffs inclosing the great depression on the south. Those on the north border of Pauline Lake are dark and massive, having the appearance of basalt, and in part consist of thick beds of agglomerate containing many volcanic bombs. The beds are inclined southward or toward Pauline Lake, and were evidently discharged by a volcano of later date than the one which was eroded to form the cliffs overlooking the lake on the south. It thus appears that the main mass of Mount Newberry is composed of the products of at least two ancient volcanoes.

Amphitheater.—The depression in the summit of Mount Newberry, measured from crest to crest, is by estimate about 5 miles from north to south and 4 miles from east to west. The walls forming its inner slopes are precipitous on all sides except the northwest, and, as stated above, rise in magnificent cliffs about its southern portion. The highest point on the rim of the depression, and the highest pinnacle of the mountain, is shown in Pl. XV, *A*, which is a view from near the outlet of Pauline Lake. The cliffs are, by estimate, 1,500 to 1,800 feet high above the lake and have conspicuous talus slopes about their bases. The rim of the basin is continuous, without a pass or deep notch throughout its entire circumference except where Pauline Creek escapes from it.

As to the origin of the amphitheater, it is to be presumed from the nature of the volcanic mountain, in the summit of which it occurs, that the latter had a crater at its top, when the eruptions which built it ceased. It may reasonably be presumed that this crater was enlarged by erosion and that a stream flowed from it toward the northwest. At a later period the depression was occupied by a névé field which gave origin to glaciers and was enlarged and given the broader features now visible by their erosion. While the amphitheater was being eaten out in the summit of the mountain, its outer slopes, particularly its south side, were becoming scored by radiating canyons. As the amphitheater increased in size, the cliffs bordering it receded, and the canyons on the outer slope lost their upper portions or were "beheaded." The glaciation of these outer canyons and their present characteristics will be noted below in connection with other records left by the former glaciers.

The dimensions and the scenic features of the great amphitheater in the summit of Mount Newberry, in which Pauline and East lakes are situated, are similar to those of the "caldera" in the summit of Mount Mazama, which holds Crater, or Mystic, Lake, already familiar from the writings of J. S. Diller and others.[a] The history of these two great depressions in the summits of mountains of about the same height and approximately of the same age is much the same, and the study of one supplements that of the other.

Lakes.—Pauline Lake, when seen from any of the commanding summits in its vicinity, appears at first to be nearly circular, but a better acquaintance with it shows that its southern portion is indented by a projecting hill of morainal material, to the east and west of which there is something of an embayment. The lake is about 2 miles in diameter from north to south and 1½ miles wide, but these are eye estimates, made in a region where there are no known distances to serve as base lines in assisting one's judgment. The water is clear and of a deep blue, with a narrow purple band, clearly distinguishable in most stages of illumination, about its margin where the depth is small. The shores are everywhere steep, except near the outlet, and in many places precipitous. Where the bordering uplands consist of glacial moraines there is a terrace, the surface of which is about 15 feet above present water level and from a few yards to a few rods wide. On the north shore at the head of a wide-mouthed embayment there is a ridge of gravel the crest of which is about 10 feet above the present fair-weather level of the lake, and there are similar gravel ridges and terraces on the southeast shore. These seem to record the upper limit to which the waves can wash the gravel on shelving shores during the most violent storms. The lake's surface is unbroken by islands, and there is a notable absence of partly submerged rocks or crags about its margin. In several places stones are piled along the shore near the fair-weather level so as to resemble artificial walls. The absence of loose stones and bowlders in the shallow marginal waters and the presence on the border of the encircling land of a ridge composed of blocks of stone much too large for the waves of the lake to move is satisfactorily accounted for by the way in which the ice of small lakes is known to shove stones ashore so as to build ramparts.[b]

No surface streams are tributary to Pauline Lake and there are only a few springs of small volume about its shores. One diminutive spring on the north border of the lake at the water's margin rises through a fissure in black rock resembling basalt, and feels hot to the hand. Its temperature is judged to be between 105° and 110° F. All other springs of the region, so far as known, are cold. With the exception of the insignificant amount of water discharged into the lake from this source, its supply comes from direct precipitation and from percolation through the open-textured or porous material forming its bordering slopes. There is a probability, however, that sublacustral springs are present, though no indications of such a source of supply are known.

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[a] Diller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper U. S. Geol. Survey, No. 3, 1902.

[b] Russell, Israel C., Lakes of North America, Ginn & Co., 1895, pp. 51–53.

As to the depth of the lake the only evidence is its uniformly deep-blue color and the generally precipitous character of its immediate banks, both of which indicate that it is deep. A line of soundings extending from near the outlet toward the center of the lake showed that in that portion the bottom is shelving and composed of pumiceous sand, but at a distance of about 600 yards from land a sounding line 125 feet in length failed to reach bottom. As shown by the color of the water when seen from many commanding stations about the lake, its margining belt of shallow water is broadest near the outlet, where the soundings mentioned were made. The character of the stream flowing from the lake is described below.

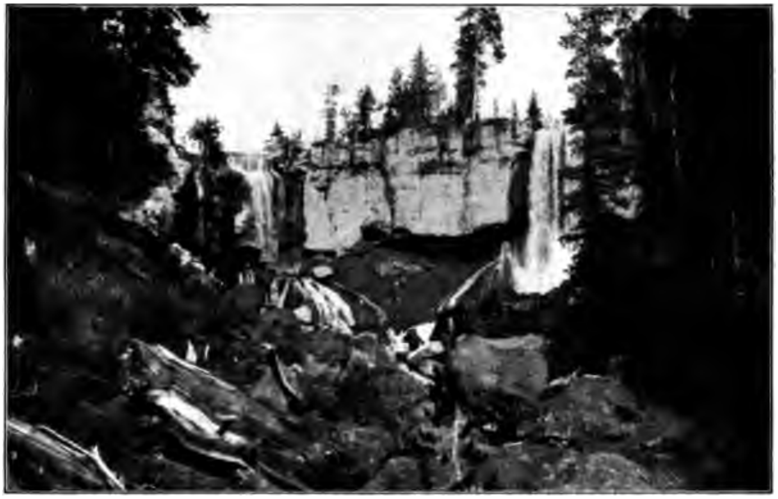
East Lake, situated in the same great amphitheater that contains Pauline Lake, is about a mile to the east of its companion, from which it is separated by a rugged lava stream composed largely of obsidian, which came into existence as described on page 98.

East Lake, like its companion, is without inflowing streams, but differs from it in not having a visible outlet and in being distinctly alkaline. Like many inclosed lakes, it bears evidence of considerable fluctuations in level, the most conspicuous record of which is a grove of dead spruce trees near its western shore which rise from about 3 feet of water. The trees are about 30 feet high, 10 to 12 inches in diameter, stand erect and still retain their branches. There is no indication that they were carried into the lake by a landslide, but every probability that they grew where they now stand and were killed by a rise of the lake which submerged the surface in which they were rooted. This conclusion needs further study, however, as no other dead trees were seen about the lake, although there were several localities where they should be expected to occur in case a recent rise of the water has taken place. Pauline and East lakes are each inhabited by swarms of insect larvæ, but are without fish. In Pauline Lake, but not observed in East Lake, crayfish are numerous, as they are also in Pauline Creek. It is of interest to note in this connection that the falls in the creek, which present an impassable barrier to the ascent of the fish which are abundant in the lower part of the same stream, are passed by the crayfish by crawling up the nearly vertical rocks adjacent to the border of the stream.

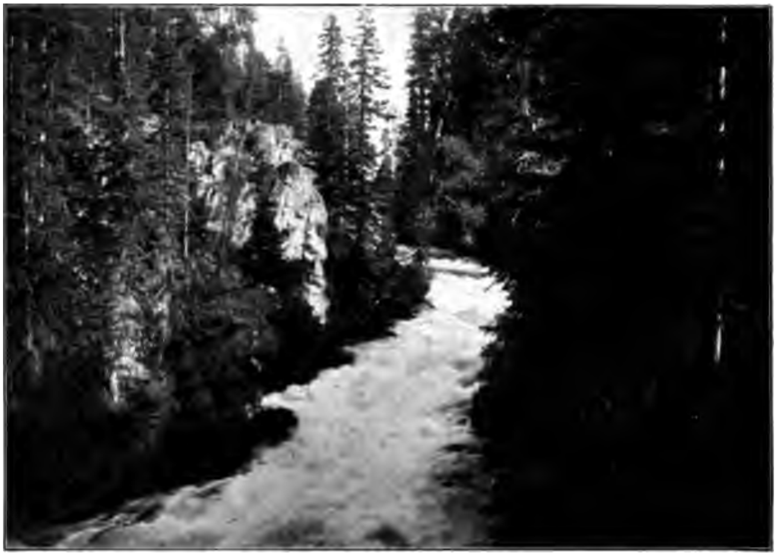
Pauline Creek.—Near where the outlet of Pauline Lake is situated the water is shallow for at least 300 yards from the shore. The adjacent land is low and in part swampy, and the outflowing stream meanders through pumiceous sand for a distance of about 600 yards to where it crosses the solid rock border of the basin. At this, the real outlet of the lake, a narrow channel has been eroded in reddish volcanic agglomerate, and the stream makes a leap of about 10 feet and enters a canyon which becomes rapidly deeper as the stream progresses. The outlet has recently been restricted in width by the building of a log dam with a water gate in its center, which permits a rough measurement of the discharge. The sill of the water gate is a log about 8 inches in diameter, laid at right angles to the current, the drop below the log being about 6 inches. The length of the gate is 11 feet. Through this imperfect weir the water flowed at the time of my visit (August 25, 1903) with a depth of 6 inches, measured by resting the end of a scale on the sill of the opening. Assuming that the conditions mentioned meet the requirements for weir measurements, they indicate a discharge of 781 cubic feet per minute.

For about half a mile below the first fall the creek flows down a canyon, which deepens rapidly and then divides into two channels, separated by a small island, and plunges over a precipice about 80 feet high (Pl. XVI, *A*), below which the canyon continues westward to the foot of the mountain. In the canyon, below the main fall, there are many rapids and small leaps of 10 to 15 feet. The layer of resistant rock which produces the main fall is composed of a reddish volcanic agglomerate about 40 feet thick, which appears to be nearly horizontal, but really has a slight dip to the east, or upstream. Below the resistant bed softer material of the same nature, also an agglomerate, occurs. The rocks about thef alls and the large angular fragments that obstruct the flow of the water in the canyon into which it plunges are rendered white by a thin nodular incrustation of calcium carbonate, precipitated from the spray of the cataract dashed and blown against them. The sides of the canyon are tree clothed and still retain their primitive wildness and beauty, unmarred by the hand of man. A conspicuous feature of the walls of the canyon where they are moistened by the spray of the cataract and of those of the creek above the precipice over which it plunges is a luxuriant growth of algæ, which mantels the rocks and forms long green streamers in the water.

Water resources.—Pauline Lake is situated in an arid region, high above the flat lands of the Deschutes Valley, and is thus favorably located to serve as a reservoir for water to be used in irrigation. As stated above, a small log dam has been placed at the head of Pauline Creek, but as it appears, for the purpose of securing some claim to the water rather than for actual use. The dam, if intact and its water gate closed, would serve to raise the level of the lake about 5 feet, but this experiment, so far as I have been able to learn, has never been tried; the reason, as I have been informed, being that when the outflow of the lake is checked wells dug in the flood plain of the creek, about 8 miles downstream from the lake, became dry. How high the waters of the lake would rise during the winter interval between



A. FALLS ON PAULINE CREEK, NEAR PAULINE LAKE.



B. BENHAM FALLS, DESCHUTES RIVER, CROOK COUNTY.

growing seasons is not known and at present can not be computed from the discharge, since the area of the lake is unknown. Taking the single measurement available, however, which was made, as is judged, during the season of least overflow, it has been estimated that the amount of water the lake could furnish if its discharge was stored for a period of nine months would be approximately 300,000,000 cubic feet, or sufficient to flood an area of 10 square miles to a depth of about 1 foot.

By dredging a channel about 600 yards in length and making a cut in soft rock about 100 feet long and 10 feet deep, arranged with a gate, and, in case the water supply is sufficient, provided also with a dam for raising the water above the present level of the lake, an admirable reservoir could be secured at small expense.

All of the conditions pertaining to the storage of water in the manner here suggested are exceedingly favorable, and there is an abundance of land along the lower course of Pauline Creek on which the water could be utilized for irrigation. The critical condition, however, and one which might render such an attempt at irrigation useless, is the extreme porosity of the deep pumiceous layer which forms the surface over all of the flat lands bordering Mount Newberry on the west. Although the belief seems to be general among the few residents of the pumice-covered region of the upper Deschutes that the porosity of the soil will render irrigation fruitless, this conclusion does not appear to have been demonstrated by experiments. It seems probable that irrigation carefully conducted would result in the compacting of the soil and the silting up of its interstices to such an extent that water would be retained at the surface in sufficient quantity to nourish plants. Without venturing to offer an opinion in this connection, however, I feel abundantly justified in recommending that a careful study of the storage capacity of Pauline Lake should be made, coupled with an investigation of the best method of conducting water to the lands to the west and a study of the soil conditions along the lower course of Pauline Creek.

Glacial records.—On the south shore of Pauline Lake, rising precipitously from the water's margin, are hills with an irregular hummocky surface, composed of unassorted rock débris, including many angular blocks from 5 to 10 or more feet in diameter, which are clearly moraines. These hills extend south to the base of the cliffs bordering the basin on that side. About the west side of Pauline Lake and merging with the moraines just mentioned there is again a broad belt of moraine-covered country which, at the north, unites with a region 5 to 10 square miles in area, situated on the mountain bordering the amphitheater in the summit of Mount Newberry on the north. The moraines on the west side of the lake rise steeply to a generally even and broad crest about 250 feet above the present lake surface, and decline westward with a well-defined slope for at least 3 or 4 miles. The full extent of the former glacier was not determined, as the region its traces occupy is so thickly forested or mantled with fallen timber that it could not be explored in the time available.

On the south side of the summit of Mount Newberry there are at least three canyon-like valleys with steep gradients, which lead southward down the outer slope of the mountain. These moderately broad steep-sloping valleys have the characteristic cross profiles of glacial troughs, such as small alpine glaciers produce, and were, without doubt, once occupied by glaciers, although no polished or striated surfaces were seen. On following them to the crest of the cliffs overlooking Pauline Lake, they were found to end abruptly at the summits of precipices several hundred feet high. These troughs will be recognized at once by persons familiar with the published descriptions of Mount Mazama, as being similar to the "beheaded" valleys of that mountain.

The interpretation of the facts just presented, arrived at while studying the region to which they pertain, is briefly as follows:

The great amphitheater in the truncated summit of Mount Newberry was in existence previous to the Glacial epoch, and during that time became filled to overflowing with snow, which formed a névé field from which a glacier from 2 to 3 miles wide flowed northwestward down the previously stream-eroded outlet of the amphitheater. During the retreat of this glacier it formed the massive terminal moraine which now unites the cliffs on the southwest side of the amphitheater with the mountain mass forming the northern border.

From the névé field in the amphitheater of Mount Newberry, the main discharge from which went toward the northwest, small ice streams found their way through notches in the line of cliffs on the south and descended preexisting canyons on the south side of the mountain, enlarging them and giving them broad U-shaped bottoms. That is, the amphitheater became so deeply filled with snow that the névé was built up at least as high as the highest pinnacle on its southern rim.

As will be seen from this explanation, the high grade and now broad-bottomed gorges on the south side of Mount Newberry are probably remnants of water-cut canyons made while the amphitheater in the summit of the mountain was being eroded; the evidence is not considered to indicate, however, that they were glaciated before the mountain was truncated or before a deep amphitheater was excavated in the portion that remained.

In connection with the statement just made in reference to the former glaciation of Mount Newberry it is of interest to note that snow still lingers throughout the summer in the noontide shadows of the cliffs on the south border of the amphitheater. At the time of my visit, August 27–30, snow banks were still present in sheltered places among the lava flows in the eastern portion of the amphitheater, at a height of less than 100 feet above Pauline Lake. It is thus evident that but a moderate climatic change in the direction of increasing the winter snowfall or of decreasing the summer melting would again bring about glacial conditions.

Recent andesite craters and lava flows.—The history of Mount Newberry thus far traced relates to the building of a lofty volcanic mountain, its truncation by erosion, the excavation of a deep amphitheater in its summit, the filling of the amphitheater with snow, the discharge from it of ice streams, and the closing of its outlet by a massive terminal moraine. Another and no less interesting chapter in the long and varied history of the mountain is recorded by material erupted from volcanoes which originated in the amphitheater vacated by the melting of the névé field.

The post-Glacial craters referred to are 5 in number, arranged in a belt running north and south across the bottom of the amphitheater, between Pauline and East lakes. The length of the belt is by estimate about 4 miles, and the position of the 5 vents along it indicate that they are situated on a fissure. Each of the 5 craters is composed of andesitic lapilli, and 4 of them discharged lava streams which on cooling produced, at least superficially, great quantities of obsidian and scoriæ. For the sake of convenience the 5 craters referred to have been assigned numbers, in reference to their positions, beginning at the north end of the series and progressing southward. In reference to their relative age, No. 3 seems to be the oldest, while No. 2 is older than No. 1; Nos. 4 and 5, the most recent of all, are of about the same age.

Crater No. 1 is situated on the southward-facing slope of the north border of the amphitheater to the northeast of Pauline Lake, from the shore of which it rises precipitously. It is not a conspicuous feature and was not visited. The principal fact concerning it to be recorded is that from a breach in the south side of its rim a lava stream was discharged which flowed south with a moderate gradient until it impinged upon the north side of Crater No. 2, where it divided, one branch going eastward toward the site of East Lake and the other branch westward toward the basin of Pauline Lake. The trunk stream and each of its branches is approximately a mile long. It was principally this lava flow which so divided the bottom of the amphitheater in which it originated as to make two basins. The end of the eastward branch forms a portion of the shore of East Lake, while its companion terminates in a steep slope washed by the waters of Pauline Lake. The surface of the lava is excessively rough and irregular, consisting of a succession of heaps of large, angular blocks of obsidian and black scoriæ together with yellowish pumice, rising from 20 to 30 feet above the general level;

between these at many localities are irregular depressions and pit-like openings fully as deep. Both the crater and the lava stream from it are densely overgrown with trees and bushes, which suggest that they are older than the similar craters, Nos. 4 and 5, which, together with their accompanying lava streams, are nearly bare of vegetation. The borders of the lava are precipitous, and in this, as in nearly all other characteristics, correspond with the streams discharged by the two craters at the south end of the series.

Crater No. 2 rises boldly near the east shore of Pauline Lake. When seen from the west shore it presents the appearance well shown in Pl. XV, *B*. The cone is, by aneroid measure, between 700 and 800 feet high, and, as shown in the picture, has a broad truncated summit. Sunk in the summit is a well-defined crater about half a mile in diameter, the south side of which has been breached by an outflowing lava stream. There is also a deep notch on the north side, but it is not so pronounced as the one opposite to it, and is not occupied by a lava stream. The cone is composed of andesitic lapilli, among which pumice is conspicuous, but this may have been showered on the crater during the eruption of the neighboring craters to the south. The outer slopes of the cone are steep and the inner slopes of the pit in its summit precipitous. The entire crater and its small lava stream are overgrown with trees.

Crater No. 3 is adjacent on the southwest to the base of Crater No. 2 and is situated near the southeast border of Pauline Lake, above which it rises to a height of about 200 feet. In comparison with its conspicuous and symmetrical neighbor it is small and its rim is deeply notched by erosion. It is probably the oldest of the group of five craters to which it belongs. Its circular form and both the inner and outer slope of its ring of lapilli are plainly recognizable, and in its bottom there is a smooth plain of yellowish pumiceous lapilli about 500 feet in diameter. This plain is similar to other pumice plains in the same region, and is formed of the same kind of material that floors the depression to the east of Crater No. 5. The walls of the crater are coated with similar material which fell after they were broken, at a date late in the history of the basin. The yellowish pumice referred to is widely scattered about Mount Newberry, and, in part at least, was blown into the air during the eruption of Crater No. 5.

Crater No. 4, situated about half a mile southeast of No. 3, is represented by a portion of its eastern rim, composed of yellowish pumiceous lapilli, which forms a curved ridge, concave to the west. Between the fragment of the crater remaining and the lava which rose within it, and now appears as a rugged, black field or plateau of obsidian, there is a deep moat, in which the water from a cold spring forms a crescent-shaped lakelet about 800 feet long and 30 to 50 feet wide. To the east of the lake is the tree-covered inner slope of the crater, and to the west the precipitous border of the stream of obsidian that rose within it but did not expand to its rim.

The west end of the fragment of the wall of Crater No. 4 disappears beneath a great sheet of black obsidian which came from the south, probably from Crater No. 5. The lavas from Craters Nos. 4 and 5 are of the same character and are united in such a manner that they seem parts of a single outpouring from No. 5. Close examination, however, shows that part of the material came from No. 4, which is several hundred feet lower than its companion and is inconspicuous except when seen from the hills of lapilli bordering it on the east.

Crater No. 5 is situated at the south end of the series, adjacent to the steep southern rim of the amphitheater excavated in the summit of Mount Newberry and about 2 miles from the southeast border of Pauline Lake. The fragments of the sharp-crested ring of lapilli which it formed during its earlier and markedly explosive eruptions are not conspicuous for their height, and, in fact, in a general view from the adjacent portion of the lofty rim of the amphitheater, are easily overlooked amid the rugged topographic forms with which they are surrounded. Sufficient of the crater rim remains, however, to show that it had a diameter of 1,500 to 2,000 feet. Within it the greatest lava discharges of any of the series of volcanoes to which it belongs took place, and in this and several other features it supplements the phenomena displayed by its companions in an instructive manner.

The lava which welled out of Crater No. 5 and buried or carried away its northwestern and northern portion for about one-half its circumference flowed northwest down a rather steep gradient for about 2 miles, but halted before reaching the site of the adjacent shore of Pauline Lake. It is in general about 1 mile wide. The lava field, or rather, the inclined plateau of rugged obsidian and scoriæ, is bordered by rough descending escarpments 50 to 80 feet high (Pl. XVII, *A*). These bordering slopes are now composed of angular blocks of obsidian that form a talus difficult to climb, which, when fresh, must have presented nearly vertical precipices. The surface of the lava is exceedingly rough, consisting of heaps and precipices of obsidian and black scoriæ, between which there are steep-sided depressions and trench-like openings, or fissures, with walls of black glass. The surface is without the general coating of pumiceous lapilli which covers practically the entire region about it, except the similar lava discharged from Crater No. 4. In common with its associated craters and lava flows it is entirely lacking in evidence to show that it was ever covered by ice, and is thus proved to be one of the most recent additions to the rocks of the Newberry amphitheater. There are no trees on the lavas, and scarcely a lichen, but on the lapilli within the craters from which it came, as shown in Pl. XVII, *B*, trees 30 or 40 feet high are growing. The absence of vegetation is evidently due to a lack of soil, and this in turn is due to the slow disintegration of the obsidian and to the open and cavernous character of the rocks, which permits dust and the finer products of disintegration to sink too deeply into them to be available for plant support.

The most novel feature of Crater No. 5, and one which is absent from its companions, is the presence in the central part of the rough lava plain it encloses of a tower-like mass of rugged and angular crags which rise about 250 feet above it. The appearance of these central crags, as seen from the southwest, is shown on Pl. XVII, *B*. The middle distance in the picture is occupied by the rough lapilli surface which forms the greater part of the floor of the crater and encircles the crags rising within it on all sides except the northwest. The crags themselves are composed of dense, granular andesite, and are without obsidian, scoriæ, or pumice, and are interpreted as having been formed by an upward protrusion of solid lava after the manner of the formation of the "obelisk" of Mount Pelee.[a]

The material occupying Crater No. 5 about the base of its central pile of crags presents interesting and novel features, inasmuch as it is composed of angular fragments that occur in irregular heaps, with equally irregular basins intervening. The surface, although generally a plain, is uneven and has hills and hollows resembling those of a glacial moraine, but is composed of angular fragments consisting of pumice, scoriæ, obsidian, and a few imperfectly shaped bombs. The explanation of this seems to be that mild steam explosions took place in it which threw it into piles, leaving depressions where the explosions occurred; after the explosions ceased cracks formed in the more solid rock beneath and permitted a subsidence of the material resting on it along certain more or less definite lines. About the border of the irregular lapilli field flooring the greater part of the crater there is a belt about 150 feet wide composed of angular and upturned blocks of obsidian and black scoriæ, of the same nature and the same general appearance as the surface of the adjacent lava flow. A portion of this broken and very rough bordering belt is shown in the foreground of the view in Pl. XVII, *B*.

A plain of pumiceous lapilli lies east of Crater No. 5, from which the pumice was no doubt blown out. This pumice plain resembles several other small basins in the same region. This sheet of pumice covers the adjacent rim of the amphitheater and is widely distributed over the neighboring plains. As it merges with other similar

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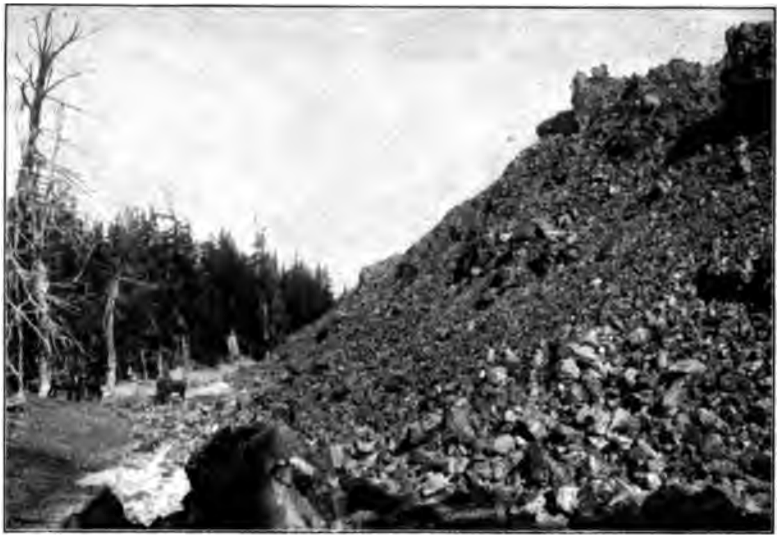
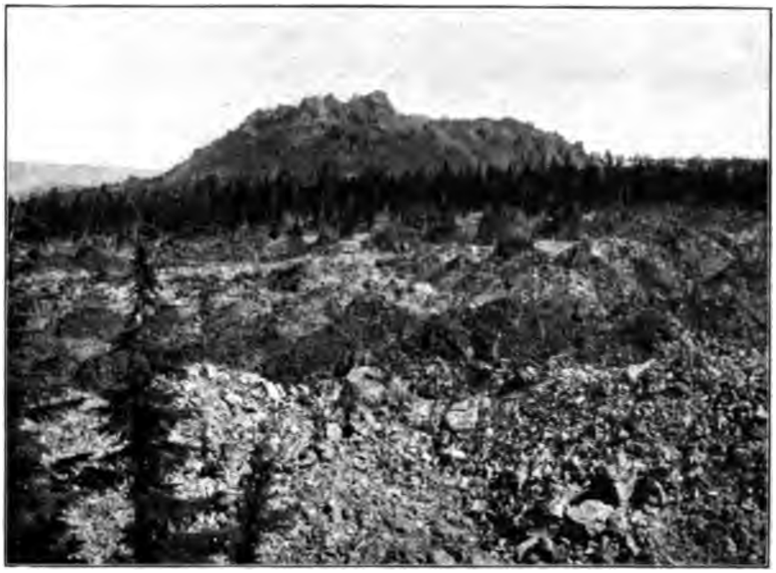
[a] Hovey, E. O., The new cone of Mont Pelé and the gorge of the Rivière Blanche, Martinique: Am. Jour. Sci., vol. 16, 1903, pp. 269–281.

Russell, I. C., The Pelé obelisk: Science, vol. 18, Dec. 18, 1903, pp. 792–795.

Russell, I. C., Criteria pertaining to massive-solid volcanic eruptions: Am. Jour. Sci., vol. 17, 1904, pp. 253–268.



A



B

VIEWS IN CRATER NO 5, MOUNT NEWBERRY.

A, Margin of obsidian lava bed, looking north; *B*, massive extrusion of lava, forming crags; looking northeast.

deposits discharged from craters in the Cascade Mountains, the limits of its distribution can not at present be stated. On Pl. XVII, *A*, the general appearance of the precipitous margin of the lava flows from craters Nos. 4 and 5 is shown. Escarpments of this nature are characteristic of the margins of all the lava flows in the amphitheater and show that the material of which they are composed was thick and viscous at the time it flowed away from the craters from which it was discharged.

The interpretation of the records made by the volcano designated as Crater No. 5 may be stated briefly as follows:

The volcano was the last (or perhaps the next to the last in case Crater No. 4, which is of about the same age, was in action at a later date) of those which originated along a fissure in the bottom of the Newberry amphitheater. Its activity at first was characterized by violent explosions, which blew out pumiceous lapilli and distributed it widely over the adjacent region, particularly on the encircling cliffs to the south and east. An encircling ring of lapilli, in general about a hundred feet high, with a sharp crest, was formed, having a diameter of approximately 1,500 feet. Later came an outwelling of thick, viscous lava which flowed northwest and expanded somewhat before cooling. The sluggish flow of this lava is indicated by the fact that it descended a slope with a well-marked gradient—about 500 feet to a mile—and came to rest with precipitous borders 50 to 80 feet high on all sides. Following the extrusion of the viscous lava came a massive-solid eruption, during which the material congealed at a considerable depth in the supplying conduit was forced up, so as to form the pile of crags in the center of the crater. That the lava composing these crags cooled and hardened at a depth and under pressure is shown by the absence of glass and scoriæ and by the incipient crystallization which resulted in a granular structure of the material. The magma which once rested on this more slowly cooled material was perhaps discharged as viscous lava, but more probably was blown away in the condition of a fragmental-solid discharge. After the central column had been forced upward and out of the summit of the conduit as a solid protrusion mild explosions occurred in the crater about its base and produced lapilli and a few bombs, which were left in heaps, with irregular depressions intervening. After the explosions ceased there was some movement in the solid rock beneath the lapilli, which caused it to become fractured.

The volcano that built Crater No. 5 thus left records of having undergone fragmental-solid, effusive, and massive-solid eruptions.

The reason for assigning the five volcanoes just described to a post-Glacial date is because, although they occur within an amphitheater which was at one time, presumably during the Glacal epoch, occupied by a névé field that gave origin to glaciers, neither their craters, composed of loose fragments, nor the rough surfaces of their lava flows bear any evidence of glaciation; without question they did not exist when their sites were occupied by flowing ice.

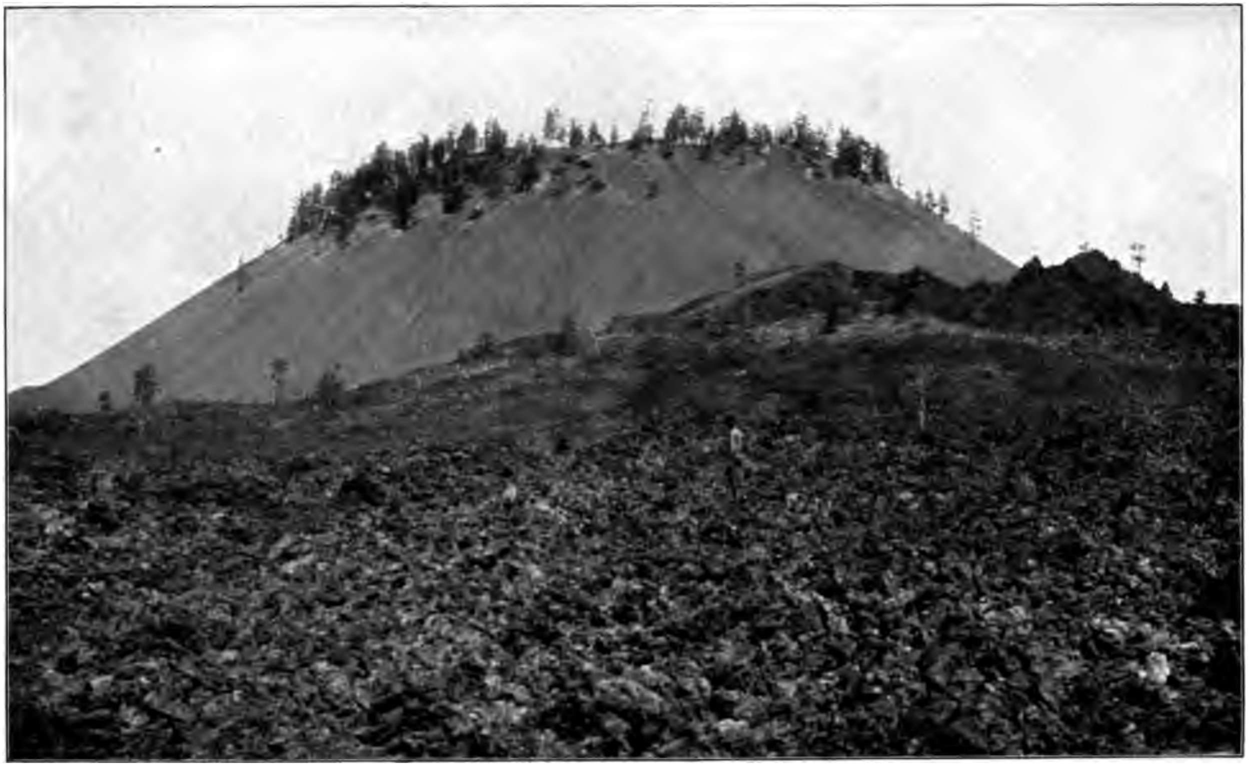
RECENT BASALTIC CRATERS.

A large number of comparatively small, black or reddish, conical elevations, some of them with depressions in their summits, are clustered about the base and on the sides of Mount Newberry, but more especially north and south of the central elevation. These secondary hills have the form and color of basaltic cinder and lapilli cones, and a long, narrow, black area 5 or 6 miles south of Mount Newberry and trending about northeast and southwest, and bare of trees, though the adjacent land is densely forested, reveals the presence of a rough lava flow, probably of basalt. Besides Lava Butte, which belongs to the same series and is described below, only one of the score or more of the recent craters referred to was visited, and that one, situated about 4 miles west of Pauline Lake, was found to be a basaltic crater built of lapilli, with a well-defined rim about 150 feet high on the outside, inclosing a depression approximately 100 feet deep and 600 feet across. This crater is in the region traversed by the glacier which flowed out of the Newberry amphitheater, and as it is unglaciated, is evidently of post-Glacial date. It is overgrown with trees, however, and is probably older than the bare, black lava stream to the south of Mount Newberry, and also older than Lava Butte, described below.

From the similarity of the several secondary craters to the north and south of Mount Newberry to the one just mentioned and to Lava Butte, it is judged that they all consist of basaltic rock and are post-Glacial in age. The score or more volcanic piles here considered are a part of a much greater group, which includes the 50 or more craters and cones in the neighborhood of Button Spring, briefly described on page 71, and also probably part of a still larger number of similar topographic forms situated to the south of Mount Newberry and known in part as the Walker Range. A vast field for the study of volcanoes, and one which will richly repay investigation, is here inviting attention.

LAVA BUTTE.

Location and general features.—Situated about 12 miles slightly west of north of Mount Newberry and about 2 miles east of Deschutes River, at Benham Falls, is Lava Butte, a conspicuous lapilli cone with a deep crater in its summit, from the south base of which a stream of basaltic lava was poured out and flowed toward the northwest at a recent date. The position of the lava flow in reference to the cone from which it came, the manner in which the lava turned



LAVA BUTTE, NEAR BENHAM FALLS, CROOK COUNTY.

Looking northeast from near south margin of lava bed.

Deschutes River aside, etc., are indicated on the following map, based on surveys made by the Pilot Butte Development Company.

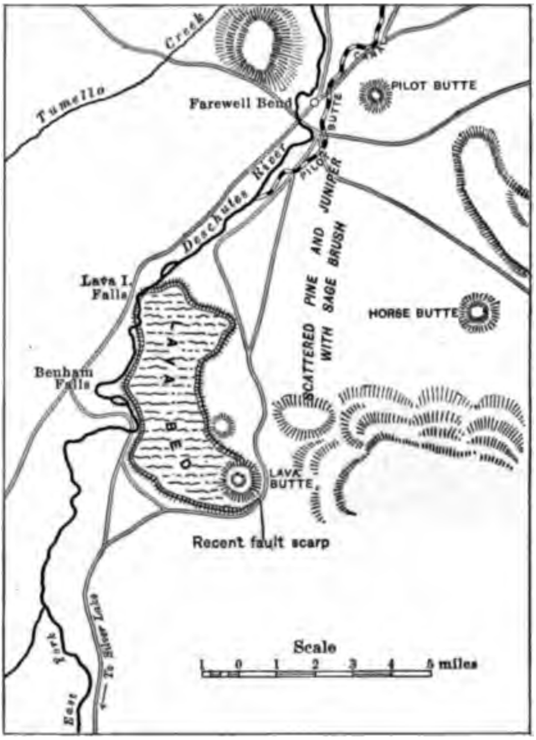


FIG. 2.—Sketch map of Lava Butte and vicinity.

Lava Butte is sparingly overgrown with pines, but the associated lava flow is nearly bare of vegetation, except that here and there a juniper tree has taken root. The scarcity of vegetation on the lava, however, is not an index of extreme youth, since trees are found upon it wherever the conditions have permitted the accumulation of sufficient soil. Dead juniper trees from 16 to 18 inches in diameter, now bleached to a silvery whiteness, which lie on it, in several instances midway down its surface, show that it was extruded at least a hundred and probably more than a hundred and fifty years ago.

The cone of Lava Butte rises about 500 feet above the adjacent forest-covered country, and is composed mainly of a coarse, angular, basaltic lapilli and scoriaceous fragments varying in size up to 3 or 4 inches in diameter. The color of this material is mostly red and black. Mingled with the angular fragments, especially within the crater, are many volcanic bombs and oval scoriaceous masses 3 or 4 feet in diameter, which were blown out as clots of viscous lava. A crater about 150 feet deep, which is situated at the summit of the butte, is without lava which rose in a fused condition, and is now partly filled with débris which has fallen from its walls and given it a conspicuous inverted-cone shape.

The appearance of Lava Butte as seen from the southwest, near the southern margin of its accompanying lava field, is shown on Pl. XVIII. As can be seen in the picture, the lava rises higher than elsewhere at the south base of the cone and stands in rugged crags. This fact is connected with one of the most instructive features that the volcanic cone and its accompanying lava stream presents, and may be considered as a contribution to the characteristics of volcanoes previously recorded.

Lava delta.—The lava escaped through the base of the lapilli cone forming Lava Butte on its south side, but did not breach it, and flowed south for a few hundred yards and then in the main curved and went toward the west and the northwest. At a late stage in the discharge of the lava it formed a " lava gutter " of the same character as the miniature examples about one of the Jordan craters, described in a previous report,[a] but was 500 feet long, about 100 feet wide at the bottom, and fully 80 feet deep. The nearly vertical walls of this black, ragged trench reveal no lava " drip," but are composed of the broken edges of thin scoriaceous lava sheets which are inclined away from the longer axis of the gutter at low angles. The steepness of the walls is due in part to disintegration, and the fall of their original surfaces. The bottom of the gutter is now a chaos of fallen fragments. From the crest of the walls of the gutter the surface slopes steeply down to the rough, but in general nearly level, bordering lava field. That is, the gutter is in the summit of an elevated ridge. At its lower or distal end it divides into three diverging gutters, with rugged crags between, one of which leads west, another south, and the third southeast.

The west distributary, as it may be termed from its analogy to a division of a river in a delta, is the smallest of the three. It is about 30 feet wide at the bottom, with vertical walls 20 to 30 feet high, on which are honeycombed or stalactite-like shapes produced by the dripping of the molten rock which adhered to them when the stream of lava ceased to flow and left its channel empty. The bottom of the gutter, when followed in the direction of the lava flow, descends sharply, and at a distance of about 500 feet merges with the surface of the lava field with which it is confluent. The lava in the bottom of the gutter is highly scoriaceous and presents swells and concentric ridges. The ridges occur in series which forms concentric parabolic or pointed curves, convex on the downstream side, and showing that the last weak discharge of lava cooled and stiffened as it flowed.

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[a] Russell, I. C., Bull. U. S. Geol. Survey No. 217, 1903, pp. 52–53.

The divisions of the main gutter that lead south and southeast from the base of the butte are in each case 50 to 60 feet wide at the bottom, and have precipitous walls 30 to 50 feet high, in which the broken edges of thin scoriaceous sheets of basalt are exposed. In a few places, however, the walls of the gutters still preserve the original coating of congealed lava which was left adhering to them when the lava streams subsided and left their channels empty. The length of the two diverging channels referred to, although indefinite, is in the neighborhood of 600 or 700 feet. Their borders are elevated ridges which slope down steeply to the adjacent lava surface, as in the case of the main or trunk channel.

The interpretation of the facts pertaining to the great lava gutter and the three separate parts into which it divides is briefly as follows:

The lava from Lava Butte escaped from it through a tunnel at its base on the south side without breaking in or in any way defacing the great pile of loose material from which it came. The explosions which blew out lapilli, clots, and bombs, and built the cone with its deep summit crater, ceased when the discharge of lava occurred, as is shown by the absence of fragmental material on the surface of the lava, although it is present on the adjacent country. The lava ran out in a liquid condition and in large volume, as a stream about 100 feet wide, on the side of which cooling and hardening took place and bordering ridges were formed. As the stream continued to flow it spread over its banks, much as an alluvial river when in flood crosses its natural levees, and the lava which thus expanded cooled and formed thin scoriaceous sheets, which increased the height of the walls bordering the lava stream and produced what may perhaps be termed "lava levees." A great gutter was thus formed which led south for about 1,000 feet, but the molten lava coursing through it broke across its confining walls in two places, in much the same manner that an alluvial river subdivides on a delta, and two distributaries of the lava stream were found, each of which also expanded laterally and formed lava levees of its own. This is the situation in brief. The entire history of the discharge and of the way in which the lava levees bordering the streams of molten rock were built is no doubt much more complex, for the earlier levees formed were buried beneath later ones and assisted in making the prominent elevation into which the lava field rises at its source, as shown on Pl. XVIII.

These gutters therefore present an example of what may be termed a "lava delta," their similarity to the work of an aggrading river being very striking. Similar topographic forms are produced in each case, but by different methods. The manner in which a lava stream overspreads its banks and makes deposits upon them is still more strikingly paralleled by brooks and rills, which in winter sometimes inundate their banks and congeal, forming ice levees.

The volcano which built Lava Butte originated on the east side of the valley of the Deschutes, where the slope was westward. The nature of this slope is revealed in the forested region immediately south of the butte, where a sheet of old basaltic lava forms the surface. The lava discharged by the volcano came from an opening on the south side of the lapilli cone it built, and at first flowed south, but, owing to the inclination of the surface over which it advanced, soon turned and advanced westward into the valley of the Deschutes, which it occupied from side to side, damming the river and extending northward down the valley for a distance of between 5 and 6 miles.

The lava was liquid and no doubt flowed rapidly, but a surface crust formed and became broken by the energetic underflow, and the blocks and cakes produced were carried along and pushed up into heaps, so as to form a typical "aa" surface, as such rough-faced lava streams are termed on the Hawaiian Islands. The roughness of the surface of the lava may be judged to some extent from its appearance as shown in Pl. XVIII. Owing to the large proportion of solid lava involved in the still liquid or viscous portion, the stream, as it advanced and expanded, became sluggish and cooled with a precipitous border in general 30 to 50 feet high. The bold angular escarpment margining the lava field on all sides is composed of angular masses of scoriaceous lava, formed by pushing along the broken fragments of the crust, which hardened before the motion in the deeper portion of the stream ceased, and has suffered but little disintegration or decay since it came to rest. The general plan of the lava's border is excessively irregular and is characterized by the presence of angular projections from its general alignment and equally sharp and angular reentrants.

As indicated on the accompanying sketch map (fig. 2, p. 111), the lava sheet surrounds the butte from which it came on all sides except the east. The same map shows also the fact that Deschutes River meets the lava flow, is deflected from it, and on returning follows its margin for about 2½ miles. The lava completely dammed the former course of the river and caused a lake to form, which found an outlet across a ridge of acid lava, probably rhyolite, on its west border. The outflowing waters cut a deep, narrow canyon, through which the river now rushes, forming a series of cascades, known as Benham Falls (Pl. XVI, *B*). This feature of the river, and the fact that its waters spread into the lava during high-water stages, so as to regulate its flow below the obstruction, will be described a few pages later in connection with other characteristics of the Deschutes (p. 117).

Age of the lava.—The presence of pines on Lava Butte, and the occurrence of both living and dead trees on the lava flow that escaped from it, furnish evidence that the activity of the volcano ceased at least a hundred and probably more than a hundred and fifty years ago. The age of the lava flow relative to other volcanic eruptions in the same region is recorded in part by the presence on the country about it, but not on its surface, of pumiceous lapilli, which cover the slopes of Mount Newberry, and the moraines that form a dam across the outlet of its amphitheater, but are not present on the rhyolitic lava streams within the amphitheater. Lava Butte and its associated sheet of basalt, like the obsidian lavas in the amphitheater of Mount Newberry, is thus shown to have come into existence since the Glacial epoch.

Faulting.—Starting near the south base of Lava Butte and extending at least a mile southward is a fissure in the older basalt of the region, which throughout much of its course is a steep-sided trench about 15 feet wide, varying in depth from a few to 10 or 15 feet. Throughout the length of this break, as far as followed, there has been a movement of the rocks of its walls, which has resulted in raising its eastern from 10 to 30 feet higher than its western side. This fault is of recent date, and perhaps indicates the course of the break which permitted the volcanic conduit that built Lava Butte to gain the surface.

Lava tunnel.—About 2½ miles south of Lava Butte, in a nearly level forest-covered region, where the surface rocks are basaltic lava of earlier date than the lava stream discharged from the butte, there is an open trench about 400 feet long and 50 feet wide, with nearly vertical walls from 30 to 40 feet high. The trench is due to the falling in of the roof of a lava tunnel, and its bottom is composed of angular blocks of basalt variously inclined. At each end of the trench one can descend a steep slope of lava blocks and gain access to portions of the tunnel where the roof is still in place, though the tunnel for several hundred feet on each side of the gap is heavily encumbered with blocks of rock that have fallen from the roof. Farther in, I am informed, where but little dislodgment of blocks of rock from the roof has occurred, the bottom of the tunnel is a level floor of pumiceous sand. It is also stated by parties who have explored the northern extension of the cavern that it can be traversed for a distance of about 2 miles.

This tunnel is like several others in the same region, and is due to the outflow of a lava stream after a roof from 30 to 40 feet thick had been formed by the cooling of the lava above it.

ASSOCIATED CONES.

From the top of Lava Butte a fine view may be had of the surrounding forest-covered region and of the desolate lava field bordering it on the west, as well as of the valley of the Deschutes, the dark eastern slopes of the Cascade Mountains, and the several fine snow peaks that crown their summit. One of the most instructive features of this far-reaching view is furnished by the numerous conical hills to the south. In the direction mentioned, within a radius of about 15 miles, 42 conical hills, ranging from perhaps 250 to 500 feet in height, were counted. These are all recent volcanic cones and craters, but are now forest-covered. In traversing this region still other similar volcanic piles were observed, and their total number must approach, and perhaps exceed, 100. This is but a part, however, of a region some 1,500 to 2,000 square miles in area, extending eastward beyond Christmas Lake, south at least to the Walker Range, and west to the volcanoes of the Cascade Mountains, which is studded nearly everywhere with small volcanic cones, most of which are believed to be composed of basaltic rocks and to be of the type of Lava Butte.

BENHAM FALLS.

The lava stream from Lava Butte, as already described, entered the valley of Deschutes River and formed a dam. The river, thus turned aside, began to erode a new channel across a spur of the old acid lava, which previous to the change formed part of its west bank. The new channel is about half a mile long, and as the task of deepening it to the depth of the old one is as yet incomplete the waters form a series of rapids, to which the name Benham Falls has been given. A picture of this interesting locality is presented on Pl. XVI, *B*, and the relation of the lava to the river is shown on the sketch map on page 111, (fig. 2). The fact that the river has not as yet deepened its present channel to the depth of the adjacent portion of the old channel now occupied by recent basalt is also shown by its sluggish flow above the obstructions, where the still water is from 10 to 15 feet deep. For about one-half mile above the head of Benham Falls and for approximately 3 miles downstream from the foot of the rapids designated by that name the river is margined on the east by a rough, precipitous escarpment of fresh, black, basaltic lava about 40 feet high, which is cavernous and intersected by fissures. The river seems to have filled the interstices in the rock adjacent to the fresh lava over which it flows during ordinary stages, but when a slight rise is experienced the water, after gaining a certain level, escapes into the lava and disappears from sight. At several localities along the border of the recent lava the water of the river, during my visit late in August, was observed flowing into crevices in the rocks along the border of the stream, and it was apparent that a tendency in the river to rise would be efficiently checked in this manner. The greater the volume of the river the more efficient these natural subterranean spillways become. The water on escaping from the river finds its way through or beneath the lava, and, as there are good reasons for believing, again comes to the light, in part at least, in the bottoms of the canyons of Deschutes and Crooked rivers, at a distance of 30 to 40 miles to the north of the localities where it disappears. Opal Spring and other similar springs in the canyon of Crooked River, described on page 88, may reasonably be explained on this hypothesis.

The efficient check on the rise of the waters of the Deschutes so provided exerts a conspicuous influence all the way down its course below Benham Falls to the mouth of Crooked River, a distance of about 50 miles. The annual range in the height of the river throughout this section is only 8 or 10 inches, while above Benham Falls the seasonal variations in the surface level of the river amount to several feet.

LAKES NEAR SOURCES OF DESCHUTES RIVER.

Near the sources of West Fork of Deschutes River and also at the head of the main stem of the river, sometimes designated the Middle Fork, there are beautiful lakes, still surrounded by primeval forests, which furnish instructive examples of water bodies held by dams built by glaciers or formed by lava flows. Some of the lakes referred to also give promise of becoming of importance when the settlement of Deschutes Valley has so far increased that irrigation will have become imperative.

DAVIS LAKE.

On West Fork of Deschutes, near its source, is Davis Lake, which is retained by a dam of lava of recent date. This lake was seen by me from the basaltic hills on its southern border, but was not directly examined. A brief description of it by Lieut. T. W. Symons, who visited it in 1878, which, as I learned from frontiersmen living in its vicinity, indicates its present condition, is as follows:[a]

> Climbing one day around the brow of a hill, we came in sight of another lake, cliff and tree environed and with bottom lands and meadows of great extent, with what appeared to be mud flats near the water. This lake and valley were about 12 by 6 miles in size, and took us completely by surprise, as they were evidently in the course of our West Fork and were not represented on any map. Reaching it we found at its southern end many acres of rich grass and bunches of tall willows. Following around the west shore to the north end we ascertained that there was no visible outlet. We saw the watermarks 20 feet above

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[a] U. S. Geol. Surv. W. One Hundredth Mer. (Wheeler Survey), Appendix B, 1879, p. 218.

> us on the lava bluffs of the northern and northwestern shores, and camping beside these in the night we heard strange rumblings in the vast pile.
>
> We found the next day that these lava beds formed an impassable barrier extending unbroken for about 4 miles to the north, and at their end were again surprised to find, foaming out from underneath the giant bowlders, the clear, cold river that we had seen lose itself in the lake 15 miles and more to the south.

The value of Davis Lake as a storage reservoir is not clearly shown by the above description, although it at least suggests the desirability of making a survey for the purpose of determining its utility for that purpose. An alternative in this connection is presented, however, by Odell Lake, situated on the same stream, about 6 miles nearer its source.

ODELL LAKE.

This charming sheet of clear, cold water, surrounded by bold, forest-covered mountains, is located on the east side of the Cascade Mountains in proximity to their crest, and receives the water from the snow fields on Diamond Peak, the height of which is 8,807 feet. On the side of that fine, bold mountain and in view from the east side of Odell Lake there is a miniature glacier situated just above the upper limit of tree growth, which may be considered as a much-wasted remnant of an extensive ice stream that formerly flowed eastward from the same elevated region and occupied the valley in which the present lake occurs. The former glacier had several tributaries in its upper portion, and also received contributions from snow fields that covered the less imposing volcanic mountain to the northeast of Odell Lake. The ice that flowed through the previously stream-eroded valley broadened its bottom, rounded and smoothed the ledges and hills of resistant rocks on its borders, and on melting left conspicuous and well-defined lateral moraines on its sides and a series of curved, concentric, terminal moraines about its southern end. The lateral moraines on the sides of the valley slope perceptibly in the direction of ice movement; in general the highest in the series on each side of the lake has an elevation of from 1,000 to 1,500 feet above its surface. The terminal moraines which sweep across the southern end of the basin in a series of open loops are steep-sided ridges composed of bowlders and much volcanic lapilli and pumice. The innermost of the series rises precipitously from the south end of the lake, and forms the dam which retains its waters. The moraine is crossed by the stream flowing from the lake, which has excavated a narrow, steep-sided gorge across it. This gorge furnishes a favorable site for a dam, by means of which the level of the lake could be raised so as to retain all of its winter discharge.

An approximately correct cross profile of the gorge at a locality about 300 yards below where the outflowing stream leaves the lake is here presented:

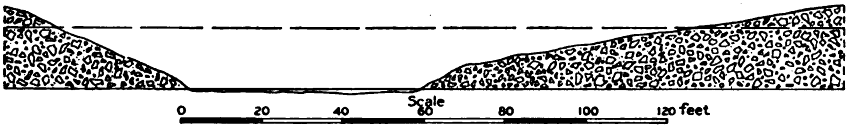


FIG. 3.—Cross profile of gorge at outlet of Odell Lake.

The width of the stream at the locality where the above cross profile was obtained was 57 feet on September 3, 1903, its average depth nine-tenths of a foot, and its maximum velocity, as determined by means of floats, seventy-five one-hundredths foot per second. These measurements show that the volume of the stream was about 31 cubic feet per second. This amount, however, is probably in excess of the actual volume, as the stream is much obstructed by stones and bowlders, and the value given to the measure of the velocity consequently too great. A better approximation to the volume of the discharge from the lake is thought to be 25 cubic feet per second. Owing to the equalizing influence of the lake, the stream flowing from it is not characterized by conspicuous variations in volume, but nevertheless there are seasonal changes to be taken into account in estimating the amount of water available for storage. The lake is said, by persons familiar with it, to rise in winter and spring from 8 to 10 inches above its summer stage, and with such a rise the volume of the outflowing stream can be reasonably assumed to be about three times its volume during its lowest stage, but for what length of time the high-water stage continues is unknown. We can, however, from the data in hand, obtain some idea of the possibilities of the lake as a storage reservoir.

The discharge given above—namely, 25 cubic feet per second—during a period of nine months, the usual interval between the seasonal periods during which water is desired for irrigation, would be 583,000,000 cubic feet. The lake has approximately an area of 6½ square miles, or 181,000,000 square feet, and an increase in its volume by the amount just mentioned would raise its surface about 3 feet. If the winter and spring discharge per second is, during certain periods, three times the lowest summer outflow—and this seems all that the conditions indicate—it is safe in endeavoring to obtain a preliminary idea of the possibilities of the lake for irrigation purposes to assume that the mean discharge during the winter season is not more than three times the mean summer outflow. On this assumption, in case all of the winter water is retained in the lake, its surface would be raised about 9 feet. This is certainly a liberal estimate, and, besides, takes no account of loss by evaporation. In considering the question of how high to build a dam in order to retain all of the winter run-off allowance should be made for probable seasons of more than normal precipitation, and also for the influence of gales blowing down the lake in raising the water at its southern end. Data in these connections are wanting, but, allowing for all probable contingencies, I venture to assume that a dam 15 feet high above the present bed of the outflowing stream, at the locality where the above cross section was obtained, would be all that would be required. A dam of this height, as shown by a broken line on the profile in fig. 3, would have an exposed crest about 160 feet in length.

The material which would have to be excavated to secure a foundation for such a dam is composed of bowlders and angular stones of various sizes up to 3 or more feet in diameter, between which there is compact volcanic sand, pumice, etc. Whether clay is present or not is unknown. The depth of the moraine is such that it is impracticable to reach a solid rock bottom in excavating for a dam, and the depth of the base of the dam below the present stream bed and the length of the lateral extensions required in order to counteract percolation can only be judged when excavations shall have been made. No great difficulty in this connection, however, can reasonably be anticipated.

The lowest sag in the crest of the moraine which retains the lake, as determined by means of a hand level, is between 55 and 56 feet. This, next after the gorge occupied by the outflowing stream, is the lowest notch in the rim of the basin.

The above measurements and estimates, although only approximately correct, will, I think, serve to indicate the nature of the problems to be studied when Odell Lake comes into demand as a storage reservoir.

CRESCENT LAKE.

Situated approximately 4 miles southwest of Odell Lake is Crescent Lake, the source of Main, or Middle, Fork of Deschutes River. This lake is larger and in nearly every way finer than its neighboring water body, and, like it, is surrounded by beautiful scenery and magnificent forests. As nearly as can be judged from the map of the Cascade Range Forest Reserve made by the United States Geological Survey, Crescent Lake is about 4 miles long and 2 miles wide. Its area is not far from 7 square miles. It is retained by a strong, well-defined terminal moraine, which sweeps across the valley in a graceful curve, presenting its concave side to the west, the direction from which came the glacier that built it. The moraine at the immediate border of the lake is one of a series having a breadth of about 2 miles, which unites with the similar series of ridges about the south end of Odell Lake. These moraines are composed of large bowlders, mingled with which is considerable pumiceous lapilli of the same character as the fragments that cover a large portion of the Cascade Mountains in southern Oregon.

The outlet of Crescent Lake is at the north end of the moraine that confines it, where the outflowing waters have cut a gorge of the same character as, but broader than, the one excavated by the stream flowing from Odell Lake. A cross profile of the gorge, made by means of a tapeline and hand level at a locality about 100 yards below where the stream leaves the lake, is here presented:

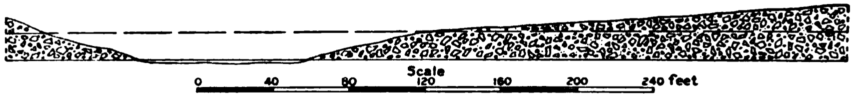


FIG. 4.—Cross profile of gorge at outlet of Crescent Lake.

The width of the stream is 89 feet, and its average depth on September 4, 1903, as shown by 15 measurements, was nine-tenths of a foot. This may safely be taken as its minimum depth during the year. The channel is much encumbered with bowlders and driftwood, so that even an approximately accurate measurement of the velocity of the stream by means of floats is impracticable. Trials in this direction, however, gave a velocity of about 1 foot in three seconds, which, together with the other measures, indicates a volume of about 21 cubic feet per second. But as the stream is plainly of greater volume than the one flowing from Odell Lake, this measure is no doubt too small. Crescent Lake, as reported by frontiersmen familiar with it, rises in March and April about 10 inches above its lowest stage, which occurs in September. These statements are in harmony with the evidence furnished by the beaches about the borders of the lake and by the downward limit of vegetation on its shores.

Not only is Crescent Lake larger than Odell Lake, but the area of mountainous land draining to it is greater, while the rainfall is essentially the same, each lake receiving some of the precipitation falling on Diamond Peak, the highest elevation in the region. Thus in many ways it is more favorably circumstanced than its companion to serve as a storage reservoir. Judgment based on all available data, and giving due weight to the inadequacy and inaccuracy of the information in hand, indicates that a dam 15 feet high would be all that is required to control the winter run-off of the lake. Such a dam, as indicated by a broken line on the profile given above, would need to be about 200 feet in length.

It must be remembered that in presenting these crude estimates my aim is simply to indicate possibilities and to recommend surveys, such suggestions being some of the functions of a reconnaissance.

WELLS.

With reference to obtaining water by means of artesian wells in the portion of the basin of the Deschutes under consideration, I failed to find any favorable evidence so far as deep wells are concerned. In the material swept out of gorges in the mountains and deposited as alluvial fans near their mouths, it is possible that small supplies of flowing water in some instances may be obtained. Conditions of this nature occur about Sisters, and in other similar situations along the eastern base of the Cascade Mountains, but no predictions as to the success of wells in such localities are at present warrantable. The structure of these alluvial deposits is unknown, and at best must be irregular. The only method of ascertaining their artesian possibilities is by sinking wells to a depth of a few hundred feet on the lower portions of the alluvial slopes, and thus ascertaining the local conditions by trial.

IRRIGABLE LANDS.

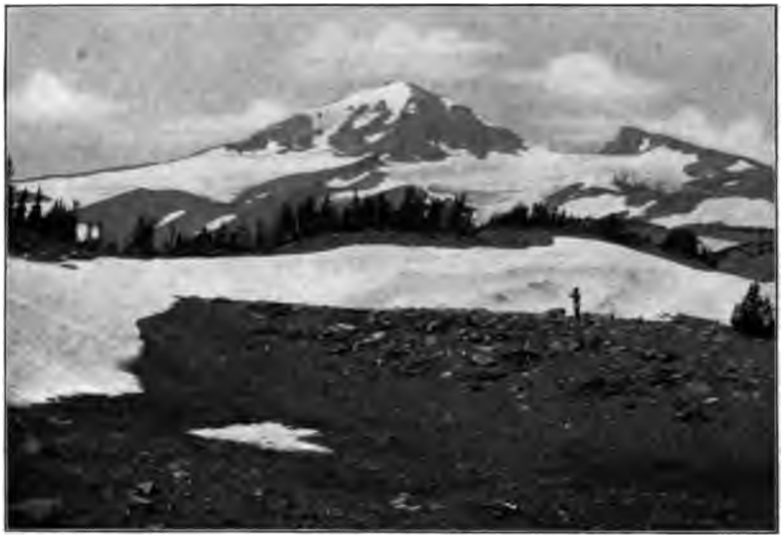
The favorable conditions for storing water, in what may be termed a small way, in the basins of Odell and Crescent lakes leads to the question: Where can the water, if stored, be utilized?

In the basin of the Deschutes above Benham Falls there is a great area of land which, as inspection indicates and private surveys are said to show, can be economically irrigated by means of ditches branching from West and Middle forks of Deschutes River. There seems no question but what, so far as engineering possibilities are concerned, there is more than enough practically level land available for the utilization of all the water that can be supplied for irrigation by the branches of the Deschutes in the region indicated above. The critical condition, however, which will evidently control most irrigation schemes in the entire drainage basin of the Deschutes above Benham Falls, is the nature of the soil.

Over all of the region just referred to, and extending far beyond its boundaries in every direction, the surface layer is composed of pumiceous lapilli, ranging in depth from about 6 feet as a minimum to over 35 feet. The exceptions to this statement occur where marsh conditions prevail and the pumice is covered or mingled with humus material; such areas, however, are comparatively small and are confined to the vicinity of the river, where they are annually or occasionally overflowed. The surface material on the uplands bordering the streams and extending over the adjacent plains and neighboring hills, is light-colored pumice, almost entirely without humus. Water conducted upon such land would almost immediately disappear beneath the surface. This absence of soil is thought by many persons familiar with the region to demonstrate the impracticability of ever

A. SOUTH SISTER PEAK.

Looking southeast.



B. WEST SISTER PEAK.

Looking west. Diller Glacier to left and Hayden Glacier to right of center.

reclaiming the land for farming purposes; others, however, equally well acquainted with the conditions, do not consider the problem so discouraging.

The reason for the absence of soil is not difficult to determine. The region is clothed with trees, but over extensive areas the primitive forest has been burned, and what are termed scrub pines have taken its place. The porous surface material dries each summer and the litter of the forest then becomes highly inflammable, and fires sweep over the land, destroying all the vegetable débris resting on it, and frequently burning the trees as well. This process has gone on year after year, in some portions of the region for an indefinite period, and no vegetable matter has been left for the formation of soil except in the low and usually wet grounds. If the land is to be reclaimed, evidently the first step is to stop the fires that now annually occur. When this is done a soil will begin to form, and by degrees forage plants will take root where now there is only bare pumiceous lapilli.

On small areas of the pumiceous land where irrigation has been practiced soil has gradually been formed and favorable crops obtained. The success of these attempts is such as to favor the conclusion that by skillful agriculture, special care being taken to supply vegetable matter to the ground, good returns can be had by irrigating the open, porous, pumiceous lands. In the nearly level region adjacent to Deschutes River above Benham Falls water can be had in wells that are only 8 or 10 feet deep even in summer, and springs are common along the border of stream channels. Thus the water table is near the surface. The springs are clear on account of the filtering their waters received while percolating through the surface layer of pumice. Their temperatures are low, approximately 50° F., or about the mean annual temperature of the region. The presence of cold water at a small depth below the surface is detrimental to agriculture, as is also the prevalence of frosts during practically every month of the year. Thus in several ways the agricultural possibilities of the region in question are confined within narrow limits.

The most that can seemingly be hoped for in the southern portion of the Deschutes basin is that its forest will be utilized and scientific forestry practiced on all of the region that can not be irrigated, and that where water can be had dairy farming and stock raising will be practicable.

GLACIERS.

During the journey which furnished the basis for this report many commanding summits were reached which furnished admirable views of the east side of the Cascade Mountains. From such distant observations, supplemented by a visit to the Three Sisters peaks, some data which seem worth recording were obtained relative to the small glaciers present about the higher summits.

EXISTING GLACIERS.

From various points of view the higher peaks of the Cascade Mountains were in sight from Mount Adams at the north to beyond Mount Pitt at the south, a distance in a straight line of over 250 miles. In this interval, in their order from the north southward, rise Mount Hood, Mount Jefferson, the Three Sisters peaks, Bachelor Mountain, and Diamond Peak, each of which has one or more small glaciers on its sides. There are other peaks which are white with snow in late summer, but so far as could be seen from the eastward are without glaciers.

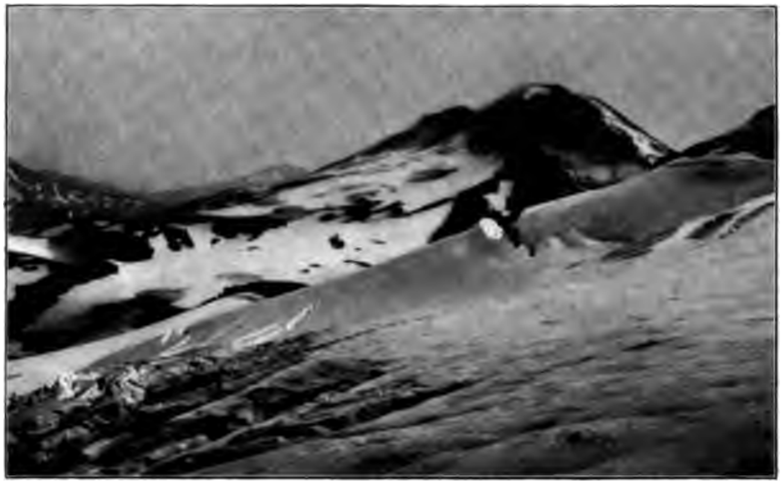
Mount Adams and Mount Hood, as is well known, have several glaciers about their higher slopes, but these were too distant from the points of view occupied during the reconnaissance to be recognized.

GLACIERS OF MOUNT JEFFERSON.

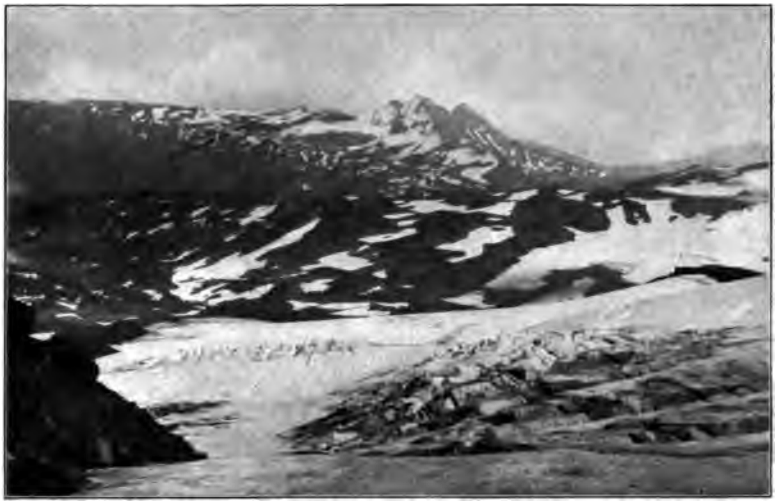
Mount Jefferson is one of the finest and perhaps the most beautiful of all the individual mountain peaks in Oregon. Standing as an immense white pyramid on the summit of the generally forest-covered Cascade Mountains, it attains a height of about 10,350 feet. The portion of the mountain rising above the upper limit of tree growth is deeply sculptured and illustrates an advanced stage in the erosion of a volcanic cone. To the northeast and to the northwest of its sharp summit are deep amphitheaters, each of which contains a small glacier. The one on the southwest side of the mountain is several hundred feet lower, vertically, than its companion and is separated from it by a prominent cliff facing southward. The névé fields of the northeast glacier extend about the northern side of the peaks and, as may be expected, coalesce with the gathering grounds of another glacier on that side. The glaciers mentioned above are intersected by blue crevasses, reveal a well-marked line between glacier proper and névé, and have marginal moraines about their borders which unite to form terminal moraines at their pointed distal ends. On the 1st of September snow banks still existed below the glaciers and in the upper portion of the adjacent forest. So far as could be determined from a distance the glaciers reveal no evidence of recent recession.

GLACIERS OF THE THREE SISTERS.

Location and size of the glaciers.—The three sharp pyramidal peaks known as the Three Sisters, which rise from the crest of the Cascade Mountains in west-central Oregon attain in each instance an

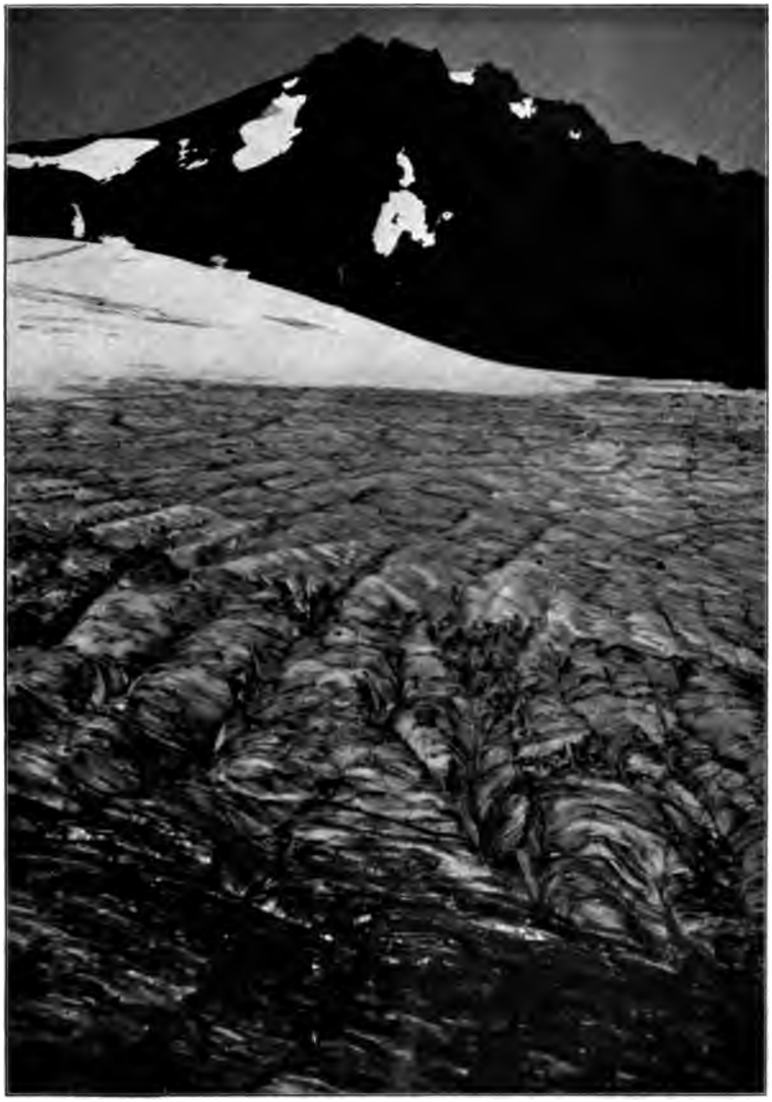


A. NÉVE OF DILLER GLACIER AND SOUTH SISTER PEAK.



B. LOWER MARGIN OF DILLER GLACIER; BROKEN TOP IN BACKGROUND.

Looking south.



LOWER MARGIN OF NÉVÉ ON HAYDEN GLACIER; NORTH SISTER PEAK IN BACKGROUND.

Looking north.

elevation of approximately 10,250 feet above the sea. The three peaks occupy the angles of a triangular space which has been excavated so as to form a great amphitheater opening east. This depression, which, measured from North to South Sister, is by estimate about 5 miles across, was formerly occupied by a large glacier which flowed eastward down the slope of the mountains for a distance of at least 10 miles and for an as yet unknown distance beyond. This glacier, on retreating, left massive moraines, which are conspicuous from certain points of view, although to a great extent obscured by the forest that covers them. The old glacier was formed by the union of several tributaries, and as it melted and withdrew within the amphitheater, where its supplying snow fields lay, it became dissected into several smaller glaciers, each of which left well-defined lateral and terminal moraines.

Within the amphitheater and well up on its sides there are at present four small glaciers—one between North and West sisters, one on the southeast slope of West Sister but in its névé portion confluent with the one on the north face of South Sister, and one on the north side of Broken Top, a rugged peak adjacent to South Sister Peak on the southeast. The general appearance of these glaciers is shown on Pls. XIX and XX.

There are also two glaciers, much smaller than those situated in the amphitheater, on the northeast side of North Sister Peak, just above the upper limit of the encircling forest. These glaciers are walled in on the lower margins by sharp-crested moraines, which rise somewhat higher than the ice they inclose, thus indicating a recent lowering of its surface. When viewed from the southeast, South Sister Peak is seen to have a long, narrow glacier of considerable size on its southeast side, which terminates at the forest line, and is not as extensive as the one on the north slope of the same peak.

All of the glaciers mentioned above are on the east side of the crest line of the Cascade Mountains, and the water supplied by their melting flows to Deschutes River; as to the snow and ice conditions on the west side of these peaks I am not informed.

The glacier between North and West Sister peaks (Pl. XIX, *B*), here named Hayden Glacier,[a] is by estimate about 1 mile long, and somewhat less in width in its broadest or névé portion. At the time of my visit, August 16, 1903, the dividing line between the hard, blue, dirt-stained ice of the glacier proper and the clean white snow of the névé was sharply defined, as may be seen on Pl. XXI. As stated above, the névé of this glacier is confluent with the névé of Diller Glacier,[b] adjacent to it on the south. The two glaciers separate at a prominent rocky crag (Pl. XIX, *B*) about 1,000 feet east of the upper margin of the névé where it meets the base of West Sister Peak. From this crag a well-defined lateral moraine extends along the margin of each glacier. These moraines are well shown on the illustration just referred to, and other characteristic glacier features are illustrated by this and other accompanying photographs.

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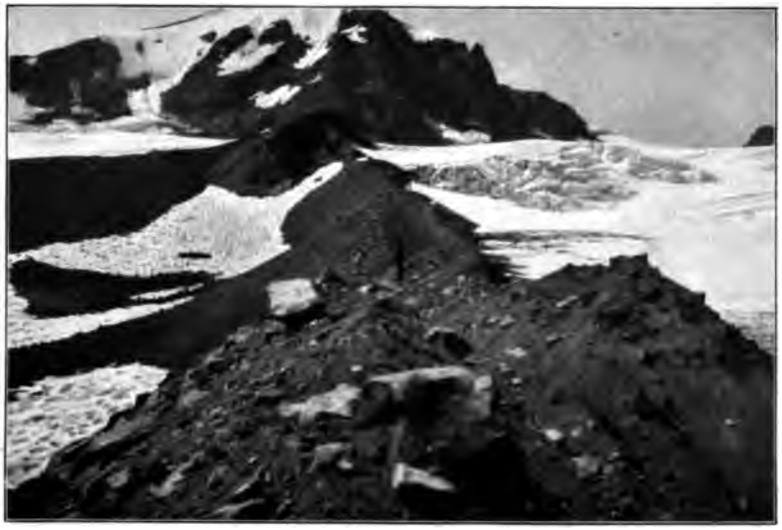
[a] Named for Lieut. E. E. Hayden, U. S. N.

[b] Named for J. S. Diller, geologist, U. S. Geol. Survey, who has carried on extensive geologic surveys in western Oregon.

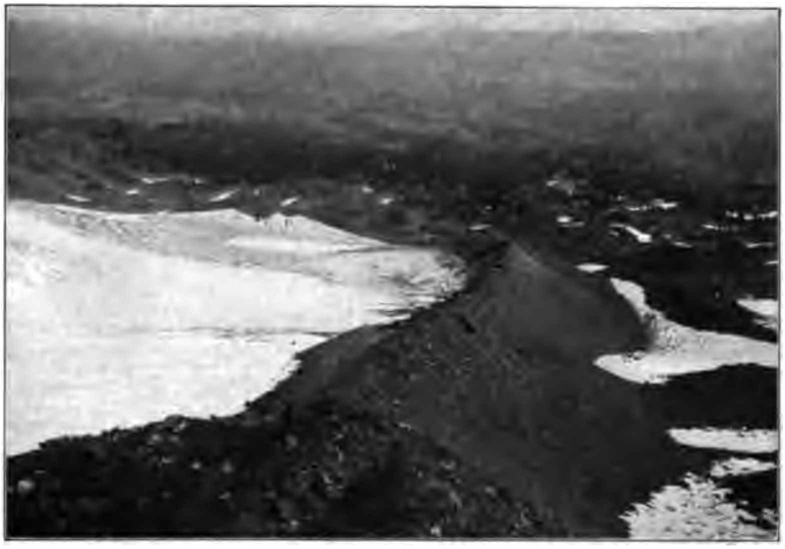
Recent shrinkage of glaciers.—The special features of interest concerning Hayden Glacier are the evidences of recent shrinkage, certain "glacier cornices" present on the wall of a crevasse near its source, and a peculiar ridge of stream-deposited gravel on the lower portion of the ice, which simulates the levees deposited by alluvial rivers.

The right lateral moraine of Hayden Glacier is steep sided and has a height of about 40 feet above the ice it margins, but the descent from its crest to its southern base is 20 to 30 feet greater. A feature of the moraine which at once attracted attention at the time of my visit was its double crest. The southern or true crest of the ridge was in general 5 or 6 feet higher than the adjacent but subordinate ridge on the north side, which was separated from it by a space of about 15 to 20 feet, there being a steep-sided trench some 4 or 5 feet deep between (Pl. XXII). Near the distal end of the double ridge, however, the inner or northern crest was higher than its companion. The explanation of the double crest is that the glacier has recently been lowered by melting about 40 feet, but its marginal portion, covered by the stones, etc., of its bordering moraine, was sheltered from the sun on account of the débris covering it and remained inclosed in the north side of the abandoned moraine. The subsequent melting of the buried ice produced a subsidence of the north side of the ridge and caused a depression to form along the crest of the ice inclosing it. As melting progresses the subordinate ridge on the north side of the true crest of the moraine will migrate down the slope of the ridge and finally disappear when the ice within the moraine is completely melted. The presence of ice in the moraine, as just described, is evidence of recent and rapid melting, and is one of the most significant records of such a change that has come under my notice. The statement just made in reference to the recency of the subsidence of the general surface of Hayden Glacier in all of its lower portion, where not thickly covered with débris, is forcibly illustrated by the fact that when viewing the right lateral moraine from the south a few fragments of ice can still be seen projecting above its crest at a locality about one-third of the way from its distal and toward its source. The appearance of the recently abandoned northern slope of the moraine under consideration is shown on Pl. XXIII, *B*.

Below the present terminus of Hayden Glacier there are fresh terminal moraines abandoned so recently that trees have not as yet



A



B

VIEWS OF DOUBLE-CRESTED MORAINE ON SOUTH SIDE OF HAYDEN GLACIER.

A, Looking west toward West Sister Peak; *B*, looking east.

taken root upon them, but they are less fresh in appearance than the totally bare double-crested lateral moraine described above.

In connection with the evidences of recent and conspicuous retreat in the case of Hayden Glacier it may be stated that its companion, Diller Glacier, which flows southwestward from the West Sister Peak, is margined by a fresh, sharp-crested moraine from which the ice has recently subsided at least 30 or 40 feet. This feature may be recognized to the left of the center on Pl. XIX, *B*. In the case of each of these glaciers the evidence noted indicates a recent lowering of their surfaces much more conspicuously than it does a decrease in their length.

Glacier cornices.—Near the head of Hayden Glacier there was at the time of my visit a crevasse of the class termed bergschrunds, a part of the lower wall of which had fallen, leaving its opposite wall fully exposed to the sun until noon, when it became shadowed and melting on its face ceased. This cliff of ice, or rather of granular névé snow, was about 26 feet high. In its face were exposed the edges of thick sheets of clear, stratified, granular snow, between which there were dirt bands ranging in thickness from a fraction of an inch to 3 or 4 inches. A view of it is shown on Pl. XXIV.

On the central part of the precipice, where fully exposed to the sun until noon each day, were two conspicuous cornices, which projected in each instance from 6 to 7 inches beyond the surface below them. The under surfaces of the projecting beds where exposed were slightly fluted at right angles to their length, but this feature was not conspicuous. The precipice at its north end passed under an arch of snow, which formed the roof of a cavern. In the portion thus sheltered from the sun there was no jutting above the lower of the two principal dirt banks, which was the only one extending into the cavern. Near the south end of the precipice, but not shown on the picture, the dirt bands were bent abruptly upward and become vertical near where the névé joined the steep face of the mountain. In this portion of the precipice, which was fully exposed to the sky, melting was equal on each side of the dirt bands, and these appeared as black streaks in the bottom of vertical V-shaped grooves 5 to 6 inches deep.

In the instances described above it is evident that the cornices are due to the more rapid melting of the layer of snow below a dirt band than of the layer above it. The evidence sustaining this conclusion is, briefly, that when a horizontal dirt band is traced from where it is exposed to the sun, and has a cornice above it, into a cavern, where the sun's rays do not exert a direct influence, the cornice disappears; and when followed to where it is vertical and fully exposed to the sky, melting is equal on each side.

The more rapid melting of the snow below than above a horizontal dirt band is evidently due to the absorption of the sun's heat by the dark material, as it is dislodged and washed downward so as to slightly stain the surface beneath. The dirt exerts this influence during its passage over the surface of the exposed edges of the layers of clear snow in the face of the precipice.

In addition to the direct evidence just presented, favoring the hypothesis of differential melting to account for the development of cornices, indirect testimony in opposition to the alternative hypothesis of differential motion is furnished by the fact that the distance from the bergschrund to the head of the névé, where it meets the steep upward slope of the mountain, ranges from 50 to 200 feet, and, as is probable, there is practically no motion in the wedge of snow thus left clinging to the rocks.

Glacial levees.—At the lower end of Hayden Glacier there was, at the time of my visit, an interesting exhibition of stream-deposited gravel, of the nature of the well-known glacier sand cones, resting on ice and deeply trenched by the stream that deposited it. In this instance gravel was deposited on the ice to a depth of 8 to 12 inches, and for a distance of approximately 150 feet the breadth of the deposit was 15 or 20 feet. The sheet of gravel sheltered the ice beneath and retarded its melting, so that it was left in relief as the adjacent surface of clear ice wasted away, but the stream which deposited the gravel held its position and caused a channel to be melted out along the crest of the ridge, down which it continued to flow as a small torrent during the hours of melting each day. The stream was thus flowing in a trench in the top of a gravel ridge at an elevation of 3 or 4 feet above the general level of the surrounding ice, and resembled an alluvial stream which has formed natural levees along its sides. This analogy in conditions suggests the term glacier levees for raised gravel ridges margining the stream flowing over glaciers, like those shown on the accompanying illustration.

The facts here recorded concerning the recent lowering of the surface in the case of two of the glaciers about the Three Sisters peaks, the explanation of the origin of the glacier cornices described, and the gravel ridges which simulate the natural levees of alluvial rivers, are matters of interest to special students of glaciers, but are by no means all of the instructive features presented by the glaciers under consideration. The Three Sisters peaks, in fact, furnish conspicuous examples of nearly all the characteristic features of alpine glaciers and of the topographic changes such glaciers produce, but to describe them in detail would lead to much repetition of what is already to be found in books descriptive of glaciers in general.[a] The

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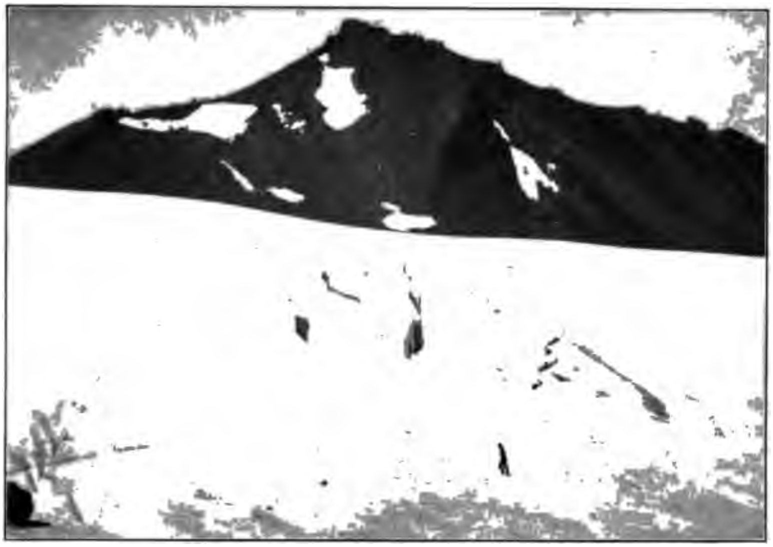
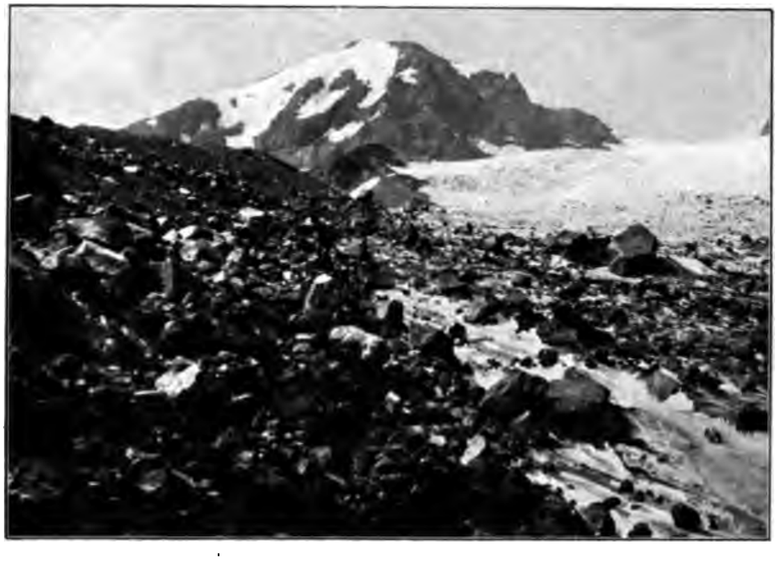
[a] Russell, I. C., Glaciers of North America, Ginn & Co., Boston, 1897.



A. NORTH SISTER PEAK AND NÉVÉ OF HAYDEN GLACIER.

Looking north.



B. RECENTLY ABANDONED MORAINE ON SOUTH SIDE OF HAYDEN GLACIER; WEST SISTER PEAK IN BACKGROUND.

Looking west.

Three Sisters peaks are also attractive on account of the admirable manner in which they illustrate an advanced stage in the erosion of volcanic cones, as well as for their fine scenery, and furnish a most inviting field for a summer school of geography, geology, and forestry.

FORMER GLACIERS.

As is well known, the mountains in the western portion of the United States were formerly much more extensively occupied by glaciers than at present. Studies in this direction have been made in the Sierra Nevada and in the portion of the Cascade Mountains which crosses the State of Washington, but in Oregon very little has been done in the way of recording the data pertaining to the former glaciers that covered them, and scarcely anything is known, particularly in reference to the glaciers that descended the east slopes of the range. It is on account of the almost total lack of information concerning the glacial records in Oregon to the east of the crest line of the Cascade Mountains that attention is here directed to the few isolated observations in that connection obtained during the recent journey.

RECORDS OF GLACIERS.

The amphitheater on the sides of the culminating pyramid of Mount Jefferson, although seen only from a distance, is evidently due in large part to glacial erosion, and bears evidence of a former much greater extension of glacial ice about that superb mountain than is at present the case.

The presence of strong moraines, both lateral and terminal, on the east side of the Three Sisters peaks has already been mentioned. These moraines show that the great amphitheater opening eastward, on the rim of which the peaks just mentioned, together with Broken Top, are situated, was formerly occupied by an extensive névé, from which a large glacier flowed eastward for at least 10 miles. This glacier probably reached the site of the village known as Sisters, but its maximum extension is as yet unknown.

Other glacial records, as already noted, occur on the east side of Diamond Peak, and show that larger alpine glaciers formerly occupied the basins of Odell and Crescent lakes. Still farther south, as has been recorded by J. S. Diller and others, extensive glaciers occupied the region about Mount Mazama. This region was traversed by me during my recent journey, and evidences of more extensive glaciation obtained than have previously been recorded. Between the Klamath marshes and the valley of the Klamath lakes there is a moraine-covered region about 10 miles broad which exhibits the well-known topographic characteristics of glacial deposits. This truly great moraine starts from the elevated region between Mount Scott and Mount Mazama, extends at least 15 miles to the southeast, and forms the bold eastern margin of Klamath Valley in the vicinity of Fort Klamath. The moraine obstructs the drainage of the region about the Klamath marshes and forms a dam through which Williamson River has cut a steep-sided gorge. Only a cursory examination of this extensive region of glaciation was obtained, but from the observations made it is evident that Klamath Valley was formerly occupied by a great glacier having several important tributary ice streams on the mountains from which it flowed. How far to the southeast the glacier extended is unknown, but it evidently occupied a part and possibly the whole of the basin in which the Klamath lakes are situated.

EXTENT OF FORMER GLACIERS.

The observations relative to the glaciation of the Cascade Mountains, just mentioned, although few and fragmentary, taken in connection with evidences of glaciation revealed by the topography of the higher portion of the range as seen from the east, and other related evidence, shows that during a former period, which can be safely correlated with the Glacial epoch, great snow fields covered the summit portion of the Cascade Mountains throughout their entire extent across Oregon, and from this névé region large alpine glaciers flowed eastward down the mountains. Glaciers also occurred on the west side of the range, but no new facts concerning them can be presented at this time. The conditions were of the same general character as existed on the Cascade Mountains in Washington,[a] but the eastward-flowing ice streams were seemingly less extensive. An instructive suggestion in reference to the glaciers on the east side of the Cascade Mountains in Oregon is furnished by the fact that in the southern portion of the State, in the vicinity of Mounts Scott and Mazama, the eastward-flowing glaciers are larger and of greater length than farther north in the vicinity of the Three Sisters peaks and Mount Jefferson. If this conclusion is sustained by future studies, an explanation of it will perhaps be suggested by comparing the present climatic conditions of the two regions.

A conspicuous feature of the topography of the higher peaks of the Cascade Range is the presence of a terrace-like shelf or shoulder about several of them at an elevation of about 8,000 feet and approximately coinciding with the cold tree-line and also with the lower limit of the existing glaciers. A flattening of the mountain side in the manner just referred to, is a noticeable feature of Mount Jefferson,

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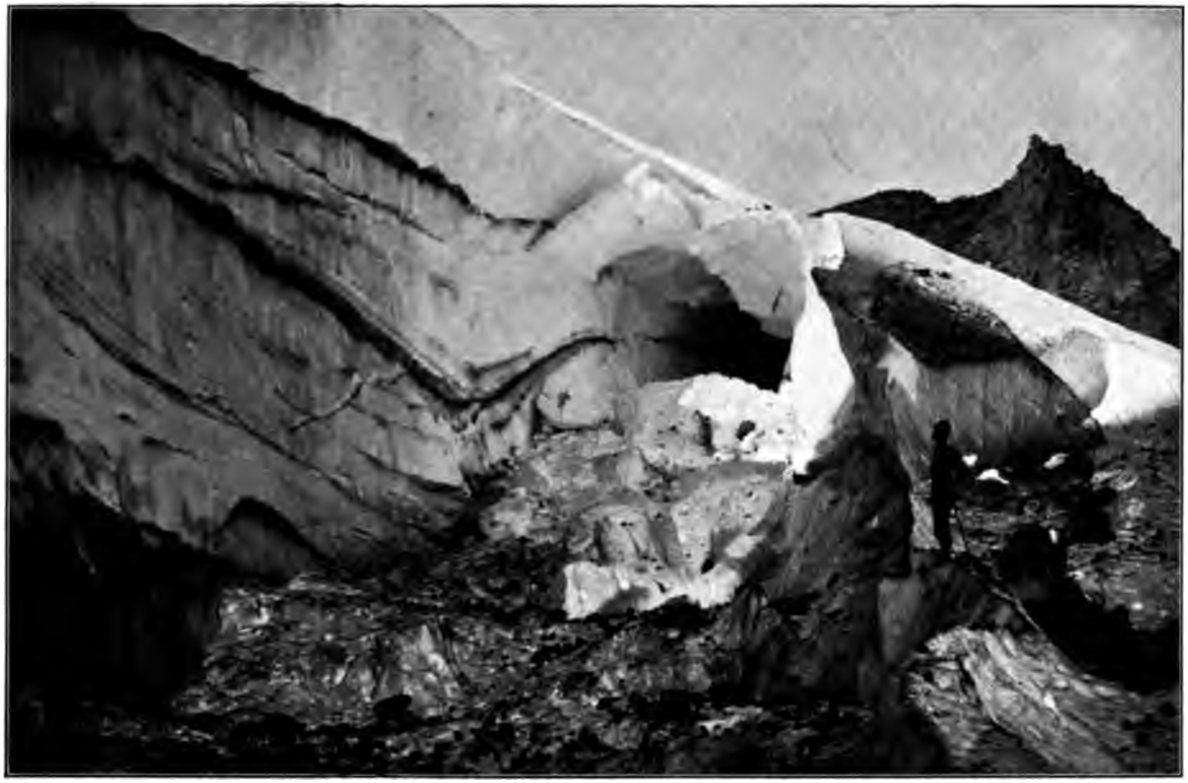
[a] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 150–193.



GLACIER CORNICES ON WALL OF CREVASSE AT HEAD OF HAYDEN GLACIER.

Looking north.

and of South Sister Peak (see Pl. XIX,A), as well as several other of the higher summits. The explanation of the origin of the shoulders seems to be that during some former time, when the conditions for the formation of glaciers were more favorable than now, "mountain-side glaciers" were formed about the higher peaks and descended their sides to where the lower margins of the shoulders are located, and by headward extension excavated depressions for themselves. When a peak was entirely surrounded by névé fields, a flattening of the slopes of the mountain resulted and was left as a topographic feature when the glaciers melted; when the névé fields were local individual recesses or cirques were produced, and when a more advanced stage of glacier work was reached "hanging valleys" were excavated. The existing glaciers of the Cascade Mountains in Oregon are, at least in a general way, situated on the shoulders referred to and seem to be broadening them by reason of their headward extension.

In connection with the former great extent of the glaciers of the Cascade Mountains, an instructive fact is furnished by the presence of extensive moraines on Mount Newberry, a brief account of which has already been given. So far as is at present known this small isolated center of glacial dispersion, and a similar area of glacial ice on Steins Mountains, in southeast Oregon, were the only glaciers in the central and eastern portions of the State during the Glacial epoch. Mount Newberry is about 40 and Steins Mountains are approximately 175 miles east of the crest of the Cascade Mountains.

LAPILLI SHEET.

EXTENT AND DEPTH.

On the preceding pages several references have been made to a surface covering of pumiceous lapilli which is widely distributed over west-central Oregon. This sheet of loose, unconsolidated fragments of pumice was first clearly recognized during my recent journey on the Great Sandy Desert to the south of Hampton Butte. It was also observed at many localities about the Pauline Mountains and in the vicinity of Christmas Lake, where it has been drifted by the wind into extensive dunes. It is present in large quantities about Mount Newberry, occurs on the moraine about the Three Sisters peaks, covers deeply the region drained by Deschutes River above Benham Falls, is present in the moraines about Odell and Crescent lakes, is everywhere conspicuous on the flat country about the Klamath marshes, forms a part of the extensive moraines adjacent to Klamath Valley on the east, occurs on the slopes and occupies the gulches about Mounts Scott and Mazama, as has been described by J. S. Diller, and southwest of Crater Lake extends for at least 30 miles west of the crest of the Cascade Mountains. Its known extent is thus about 120 miles from east to west and an equal distance from north to south, or an area of 14,000 square miles. Its actual borders when finally determined will, there is no doubt, be found much to exceed these limits.

The depth of the sheet of pumice varies from place to place, and in only a few localities is its actual thickness known. Its depth is probably greatest in the valleys and least on the steep slopes. Although, like a fall of snow, it originally fell evenly over the surface, though more abundantly and in larger fragments near the volcanoes from which it came than at a distance, it has since been washed down from inclined surfaces and concentrated in depressions. On the Great Sandy Desert excavations 70 feet deep are said to have failed to pass through it. In the generally flat country drained by the Deschutes above Benham Falls excavations show its minimum depth to be from 6 to 8 feet, but in many places and over large areas it is much thicker. In the extensive region north of the Klamath marshes and draining to them, the banks of streams and bluffs above copious springs in several places reveal a thickness of 30 to 40 feet or more of pumice, the bottom of the deposit being still concealed. In describing the sheet of pumice about Crater Lake, Diller[a] mentions a thickness of 10 feet. While conspicuous variation in thickness occurs and no average depth can as yet be stated, the above-mentioned facts show that the volume of the deposit is very great, so great in fact that it is to be measured in tens of cubic miles.

COMPOSITION, SOURCE, AND AGE OF LAPILLI SHEET.

The sheet of pumice just described is composed of rough angular fragments, which on the Great Sandy Desert range in size from dust particles up to grains that are about one-fourth or perhaps one-half of an inch in diameter. It is much coarser about Mount Newberry, where fragments a foot in diameter were seen, but so far as now known the fragments are largest on the flat country adjacent to the Klamath marshes on the west, where angular masses more than 2 feet in diameter are common. The pumice, as shown by determinations made by F. C. Calkins, of the United States Geological Survey, of samples collected on the Great Sandy Desert, on Mount Newberry, and near the Klamath marshes, is andesite. About Crater Lake the surface sheet of pumice is described by J. S. Diller as being principally dacite, with less quantities of andesite. The observations available are too few to permit a final statement, but the facts in hand seem to indicate that the sheet of pumice under consideration is tolerably uniform in character and composed principally of andesite.

As to the location of the volcanoes from which the pumice was blown into the air and widely distributed, for the most part only tentative suggestion can at present be offered. In part it came from the recent volcanoes, five in number, situated in the old erosion amphitheater of Mount Newberry. This conclusion is based on the fact that the crater rims of those volcanoes are largely composed of andesitic pumice, and large fragments of the same nature are abundant all about the region where they occur. This was probably not the only center of dispersion, however, as the fragments of pumice are still larger and more abundant in the region draining to the Klamath marshes, and, as stated by Diller, were supplied at least in part by eruptions in the great depression now occupied by Crater Lake.

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[a] Diller, J. S., and Patton, H. B., Geology and petrography of Crater Lake National Park: Prof. Paper U. S. Geol. Survey No. 3, 1902, pp. 39-41.

In reference to the date of the explosive volcanic eruptions that supplied such vast quantities of pumice, the fact that this material forms a large percentage of the glacial moraines on Mount Newberry, the Three Sisters peaks, and about Odell and Crescent lakes, shows that the eruption occurred previous to or during the Glacial epoch. The moraines about Mount Newberry and near the lakes just mentioned are covered with pumice, showing that at least in part the eruptions which furnished it were of later date than the glaciers which deposited the moraines. This last conclusion is sustained also by the fact that the recent lapilli craters in the old erosion amphitheater of Mount Newberry and the lava flows given out by them are clearly subsequent to the time when that depression was filled with glacial ice. According to Diller the eruptions of pumice about Crater Lake occurred during and after the time the region about it was occupied by glaciers.

IMPORTANCE OF LAPILLI SHEET.

The sheet of pumice that covers so much of central and western Oregon is thus of much scientific interest, and when its history is fully known will furnish a most instructive chapter in the geologic records of the State. It is also of great practical importance, since it forms the surface covering over thousands of square miles, and has a determining influence on the agricultural possibilities of the entire region it occupies.

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[Bulletin No. 252.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This bulletin is the fifty-seventh in Series B and the thirty-third in Series O, the complete lists of which follow. (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper.)

SERIES B, DESCRIPTIVE GEOLOGY.

B 23. Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 124 pp., 17 pls.

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The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton, Bulletin No. 138.

Correspondence should be addressed to

THE DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

FEBRUARY, 1905.

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Russell, Israel C[ook], 1852—

. . . Preliminary report on the geology and water resources of central Oregon, by Israel C. Russell. Washington, Gov't print. off., 1905.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

COMPARISON

OF

A WET AND CRUCIBLE-FIRE METHODS

FOR THE

ASSAY OF GOLD TELLURIDE ORES

WITH NOTES ON THE ERRORS OCCURRING IN THE OPERATIONS OF FIRE ASSAY AND PARTING

BY

W. F. HILLEBRAND and E. T. ALLEN

WASHINGTON
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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., November 1, 1904.

SIR: I transmit herewith, for publication as a bulletin, a paper by Messrs. W. F. Hillebrand and E. T. Allen, in which the subject of inquiry is the accuracy of the crucible assay method for telluride gold ores.

The question is a very important one in the very important telluride gold fields, and it is satisfactory to be assured that the doubts which have been entertained as to the accuracy of the dry method are not well founded.

While this main point is definitely established, the investigation as a whole is less complete than most of those which are issued from the Survey laboratories, and several problems suggested by the experiments are not fully worked out. This is due to the unfortunate fact that the quarters occupied by the Survey have become so crowded as to make it necessary, in the interest of other divisions, to abandon assaying altogether and to dismount the assay furnaces before this research had been completed.

Very respectfully,

GEORGE F. BECKER,
Geologist in Charge Division of
Chemical and Physical Research.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

COMPARISON OF A WET AND CRUCIBLE-FIRE METHODS FOR THE ASSAY OF GOLD TELLURIDE ORES, WITH NOTES ON THE ERRORS OCCURRING IN THE OPERATIONS OF FIRE ASSAY AND PARTING.

By W. F. HILLEBRAND and E. T. ALLEN.

INTRODUCTION.

The scorification assay for telluride ores has long been believed, and apparently proved, to give low results by reason of volatilization, and it is now seldom used for ores of that class. The assay by crucible is supposed to be far more reliable, and Furman[a] maintains that it is entirely so when properly carried out. He gives a very few comparative determinations by fire and wet assay in proof of his assertion, but the tests are too few in number and the agreement is not so close as might be desired. A more critical investigation of this problem seemed to promise results of some value to those engaged in mining and smelting the telluride ores which are so important in certain parts of our own and other countries, and the data and conclusions set forth in the following pages are the outcome of experiments on telluride ores from Cripple Creek, Colo. From them it will be seen that there is no occasion to question the substantial accuracy of the crucible method, as tested by careful determinations in the wet way. Incidentally the question of losses of gold in assaying, particularly during cupellation and parting, has been looked into, for concerning these points the most contradictory statements are to be found in the literature. Only after most of the work upon the ores had been completed was this fully impressed upon us and the extent of some of these losses duly appreciated. Had this appreciation come earlier we might have been able to offer still more satisfactory results for our assays.

PART I. ASSAY OF CRIPPLE CREEK TELLURIDE ORES.

NATURE OF THE ORES ASSAYED.

Efforts were made to procure two ores of somewhat widely differing gold content and, with a view to the preparation of a homogeneous sample, containing as little free gold as possible. As received, through the kindness of Mr. W. M. Bainbridge, of the El Paso Consolidated Gold Mining Company, and of Dr. Waldemar Lindgren, of the Geological Survey, the samples were marked 6 and 12 ounces per ton respectively, but they were actually much richer and of nearly equal value, approximately 15 and 19 ounces to the ton. At least 10 pounds of each was available. The ores were from a narrow fissure in granite and were themselves practically granite, carrying pyrite in some quantity, the higher grade sample *b* more than *a*, some calcite; also traces of copper and molybdenum, as shown by determinations on 100 grams. Other constituents were not looked for. The tellurium also was quantitatively determined, in 50-gram portions, in order to judge of the composition of the telluride mineral. As given below, silver is, no doubt, a trifle low, because of the impossibility of making exact allowance for loss in assaying.

---

[a] A Manual of Practical Assaying, 1899, p. 399.

TABLE I.—*Amounts of certain constituents of the ores.*

	a.	*b.*
	Per cent.	*Per cent.*
Te	0.0742	0.092
Au	.0506	.060
Ag	.0075	.0103
Cu	.0059	.0070
Mo	.0015	.0018

Assuming none of the gold and silver to be free, but all in combination with tellurium, the following percentage compositions for the telluride have been calculated from the foregoing table:

Calculated composition of the tellurides.

	a.		*b.*	
	Per cent.	*Atomic ratio.*	*Per cent.*	*Atomic ratio.*
Te	56.09	1.78	56.68	1.80
Au	38.24	1.00	36.97	1.00
Ag	5.67		6.35	
	100.00		100.00	

If the tellurium has been correctly determined, the above results indicate the probable presence of free gold, for from what we know of the occurrence of gold-silver tellurides at Cripple Creek they probably all conform to the general formula MTe_2. That the telluride here present must then be largely if not wholly sylvanite, assuming absence of other silver minerals, is indicated by the amount of silver shown by the analyses, which is considerably in excess of that in even the richest known calaverite. It is not impossible that both calaverite and sylvanite as well as free gold are present. From the ratio of gold to silver in a second pair of samples, a_1 and b_1, which, as mentioned later, were taken from a lower position in the original sample bags, so that a considerable mechanical sorting had ensued since the bags were filled, the suspicion may be justified that the silver is in part a constituent of some mineral other than a telluride. For if the assays are correct there is a diminution in the silver as the gold increases, as shown by the following comparison:

	a.	*a₁.*	*b.*	*b₁.*
	Ounces.	*Ounces.*	*Ounces.*	*Ounces.*
Ag	2.19	2.07	3.00	2.87
Au	14.53	15.60	17.75	19.63

That not all the silver may thus be assigned elsewhere is, however, likely from the fact that the ratio of tellurium to gold alone is much in excess of 2 to 1. But too much weight must not be attached to the above values for silver, and therefore speculations of this sort are of little importance.

PREPARATION OF THE SAMPLES.

Considerable portions from the tops of the bags containing the coarsely crushed samples received were ground fine enough to pass a sieve of 100 meshes to the linear inch and mixed for what was considered a sufficient time to insure homogeneity. The amounts thus prepared proved inadequate for the completion of the work, so other portions were ground fine enough to pass a sieve of 150 meshes and mixed more intimately even than in the first instance, this being done because the first results on sample *b* were somewhat less satisfactory and less accordant than those on *a*, a condition which it was hoped finer grinding would remedy. These second samples were found to be markedly richer in gold than the first, due doubtless to their having been taken from a greater depth in the original bags. They represented practically new ores, and, to simplify references, will be designated a_1 and b_1.

COMBINATION WET AND FIRE ASSAY.

Throughout the literature it is prescribed that for wet assay of gold ores they should be subjected to a preliminary roasting for the removal of sulphur chiefly. Since, however, it is pretty certain that there is loss of gold by volatilization in the roasting of telluride ores, it seemed imperative to disregard these directions and to treat chemically the unroasted ore. No attempts were made to test different methods of attack and subsequent treatment because of lack of time. The method employed in all cases was the following:

Fifty-gram portions in duplicate were mixed with water in large porcelain basins, and strong nitric acid was added by degrees with constant stirring till action had nearly ceased. Then bromine water was added in excess to oxidize the gold and sulphur and precipitate the silver. No artificial heat was employed. The following morning the insoluble matter was collected on filters and washed ten times with water containing bromine and some hydrochloric acid, then two or three times with pure water.

It was found impossible to extract the whole of the gold by wet treatment. The residues always yielded by fire assay small amounts of gold, usually under 0.1 mg. when properly washed, besides nearly all the silver.

The combined filtrates were evaporated in the original porcelain basins to near dryness, then treated with hydrochloric acid and covered for a time. When action ceased the covers were removed and evaporation continued, hydrochloric acid being added two or three times more at proper intervals. When the residues were now digested with dilute hydrochloric acid and a little bromine water, to insure solution of the gold, there remained undissolved considerable calcium sulphate, which was collected on a suitable-sized filter and the filtrate received in a beaker. The first calcium sulphate residues thus obtained were found by fire assay to be free from gold, but all those obtained in subsequent tests were added to and assayed with the main residues.

The filtrates contained all the iron in an oxidized form and a slight excess of bromine. Without attempting to reduce the ferric iron to ferrous by sulphurous acid, whereby tellurium would have been in part precipitated as well as the gold, a large excess of filtered ferrous sulphate solution was added, which induced complete precipitation of the gold alone, without any tellurium. The completeness of precipitation was proved by the failure to detect any gold in the subsequently precipitated tellurium.

After twenty-four hours the precipitated gold was collected on a 9 cm. paper filter of 0.00005 gm. ash content, carefully washed with cold water, then with warm dilute hydrochloric acid to extract iron from the paper, and finally with hot water. Paper and contents were burned in a clean porcelain crucible, and the contents most carefully transferred to the pan of the assay balance and weighed as nearly as might be to hundredths of a milligram. As a check the gold was then generally cupelled with 3 or 4 grams of pure lead in order to eliminate the error introduced by paper ash and any possible failure to wash the filter thoroughly. A companion cupellation with a similar amount of proof gold afforded the correction for gold loss during cupellation.

A number of the beads thus obtained from the ore were collectively tested most carefully for silver, with negative results.

It was said above that it was not possible to extract quite all of the gold from the ore, and that the residues insoluble in acid were treated by fire assay in order to recover the amount retained. The retention was probably owing to particles of telluride inclosed in gangue matter, or of gold in sulphur which had been separated but not fully oxidized by the treatment with nitric acid and bromine. These residues were assayed in crucibles with the following charge: Litharge, 2 A. T.; soda, 1 A. T.; borax, 10 grams; argol, 2 grams; salt, cover. The lead button thus obtained weighed about 20 grams and yielded on cupellation nearly all the silver of the ore and a small amount of gold, which latter was obtained pure by direct parting. It was not deemed necessary to examine slags or cupels for their possible gold contents, owing to the minute amount in question, nor was any attempt made to determine by the wet way the exact amount of silver that the ore held.

TABLE II.—*Combination wet and fire assays for gold in Cripple Creek ores.*

[50 grams in each case.]

Sample.	Residues.	By $FeSO_4$.	Total.		After cupellation.	
	Milligrams.	*Milligrams.*	*Milligrams.*	*Oz. per ton.*	*Milligrams.*	*Oz. per ton.*
a	0.08	25.29	25.37	14.80	....	....
	.04	25.22	25.26	14.73	25.22	14.71
	.08	25.73	25.85	15.08	[a]25.42	14.82
	.06	25.63	25.69	14.98	[a]25.30	14.76
a_1	.12	26.48	26.60	15.52	26.51	15.46
	.16	26.32	26.48	15.45	26.45	15.43
	.05	26.69	26.74	15.60	26.59	15.51
	.12	26.89	27.01	15.76	26.73	15.59
b	.13	....	....	....	....	....
	.12	29.56	29.68	17.32	29.45	17.18
	.07	30.84	30.91	18.03	30.57	17.83
	.12	30.50	30.62	17.86	30.17	17.60
b_1	.98	32.54	33.52	19.55	33.35	19.45
	.37	33.13	33.50	19.54	33.32	19.44
	.10	33.10	33.20	[b]19.58	33.07	[b]19.49
	.11	33.85	33.96		33.76	

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[a] These beads contained a very little silver, which was lost in process of parting.

[b] The assays were made in pairs, and by accident a part of the washings of one assay was evaporated in the wrong dish. The assays were run through separately, but only the mean is taken for final comparison.

There is seen to be a very fair agreement in each of the several series except *b*, an exception which was apparent also in the fire-assay tests of the ore. It was largely for this reason that fresh samples of each ore were prepared (a_1 and b_1) as before mentioned.

FIRE ASSAY.

CONDUCT OF THE ASSAY.

The assays were all made in Battersea F crucibles, heated in a gas-fed melting furnace, as the muffle available was far too small to admit crucibles of such size. A very satisfactory charge was found to be that given below, and it was adhered to throughout except in a few cases where the litharge was reduced to four assay tons without any apparent difference in results.

Ore	1 assay ton (29.166 grams).
Sodium bicarbonate	1 assay ton.
Litharge	6 assay tons.
Borax (fused)	10 grams.
Salt cover.	

Neither iron nor niter was used. In most cases the requisite amount of silver was added to give two and one-half to three times the weight of the gold. During the earlier stages of firing the temperature was purposely kept low, and it was not made high until escape of gas had nearly ceased. The buttons obtained were rather large for cupellation—about 25 grams in weight—but it was felt that by reducing a large amount of lead the collection of all the gold would be more certain. The buttons were in all cases soft and malleable. Not every slag was assayed, since it was found that the gold losses here were very slight, in direct disagreement with Fulton's results on Cripple Creek tellurides.[a]

The larger number of tests were made by one of us (A), but in order to have the check of another worker a number were made by his colleague (H). The latter's results seem to be in general a little below those of A, a fact probably explained by the employment of a somewhat higher temperature in cupellation. The powerful influence of slight changes in temperature on the cupellation results will be emphasized in the second part of this paper.

CHARGES USED IN ASSAYING SLAGS AND CUPELS.

The charge used for the slag assay was: Litharge, 1 A. T.; argol, 2 grams; salt. For cupels it was: Litharge, 2 A. T.; soda, 1 A. T.; borax glass, 1.5 A. T.; argol, 2 grams; salt.

ASSAYS FOR GOLD AND SILVER TOGETHER.

The first assays were made in order to ascertain not only the gold, but also the silver content of the ores, though no importance was attached to the determination of the latter. Incidentally these tests showed the losses of gold in slags and cupels.

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[a] Jour. Am. Chem. Soc., vol. 20, 1898, p. 596; see also later in this bulletin, p. 14.

TABLE III.—*Crucible assays of Cripple Creek telluride ores for gold and silver together.*

[Values are the weights obtained in milligrams, and denote ounces per ton of 2,000 pounds.]

Main assay, Au+Ag.		Slags.		Cupels.	
		Au+Ag.	Au.	Au+Ag.	Au.
a	16.54				
	16.37	0.07		0.10	
	16.97	.04		.07	
	16.50				
	16.58				
	16.54				
Average	16.58	.055		.085	
From slag	.055				
From cupel	.085				
Total	16.72				
Less average gold, from Table VII	14.53				
Silver	2.19				
b	20.54				
	20.63	.08	0.03	Lost.	
	20.58	.08		0.10	0.04
	20.88				
	20.21				
Average	20.57	.08	.015	.10	.04
From slag	.08				
From cupel	.10				
Total	20.75				
Less average gold	17.75				
Silver	3.00				
a_1	17.39	.43		Lost.	
	17.40	.05		0.17	
	17.43	.07		.15	
	17.25	.03		.17	
Average	17.37	.145	[a].027	.16	[a].07

[a] Averages obtained by combining all the beads (8) from a_1 and b_1.

TABLE III.—*Crucible assays of Cripple Creek telluride ores for gold and silver together*—Continued.

Main assay, Au+Ag.		Slags.		Cupels.	
		Au+Ag.	Au.	Au+Ag.	Au.
From slag	0.145				
From cupel	.16				
Total	17.675				
Less average gold	15.60				
Silver	2.075				
b_1	22.33	0.06	....	0.22	....
	22.34	.05	....	.17	....
	22.42	.06	....	.16	....
	22.38	.04	....	.18	....
Average	22.37	.05	[a]0.027	.18	[a]0.07
From slag	.05				
From cupel	.18				
Total	22.50				
Less average gold	19.63				
Silver	2.87				

[a] Averages obtained by combining all the beads (8) from a_1 and b_1.

Discussion of results.—The cupellation loss, even without that due to volatilization, is here seen to be markedly greater than in the slag. This observation is in agreement with the general tenor of statements found in the literature, but directly contradicts Fulton's statement, already referred to, as to telluride ores from Cripple Creek.[a] May not his high losses in the slag have resulted from his employment of iron nails, with resultant formation of auriferous sulphide in the slag?

In order to have a check upon the actual loss, including that due to volatilization, proof metal of the composition of that obtained from the ore was cupelled with 25 grams of lead. The results follow:

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[a] Jour. Am. Chem. Soc., vol. 20, 1898, p. 596.

TABLE IV.—*Cupellation losses on proof alloy.*

	Taken.	Found.	Loss.		Recovered from cupels.	
	Milligrams.	*Milligrams.*	*Milligrams.*	*Per cent.*	*Milligrams.*	*Per cent.*
Ag	2.09				0.06	2.87
Au	15.59				.077	.49
Au+Ag	17.68	17.53	0.15	0.85	.137	
Ag	2.26				.08	3.54
Au	15.74				.077	.49
Au+Ag	18.00	17.84	.16	.89	.157	
Ag	2.28				.07	3.07
Au	19.75				.08	.40
Au+Ag	22.03	21.51	.52	2.36	.15	
Ag	2.58				.10	3.88
Au	19.64				.07	.36
Au+Ag	22.22	22.07	.15	.68	.17	

When cupellation takes place at a low temperature, with formation of considerable feather litharge, as in the above cases, the loss by volatilization is seen to be practically negligible, or if not absolutely inconsiderable to be compensated perhaps by retention of lead, but that the case is different when the temperature is higher is plainly shown elsewhere in this paper (Tables VIII and IX).

ASSAYS FOR GOLD ALONE.

In all these cases the requisite amount of silver was added at the start to give a bead suitable for parting.

TABLE V.—*Crucible assays of Cripple Creek telluride ores for gold alone.*

[Values are the weights obtained in milligrams and denote ounces per ton of 2,000 pounds.]

Main assay, Au.			Slags.		Cupels.	
			Au+Ag.	Au.	Au+Ag.	Au.
a	14.50		0.25			
	14.42		.36			
	14.45		.16		0.72	
	14.47		.18		.82	
Average	14.46		.24	0.02	.77	0.03
From slag and cupel	.05					
Total	14.51	(Allen).				

TABLE V.—*Crucible assays of Cripple Creek telluride ores for gold alone*—Cont'd.

Main assay, Au.			Slags.		Cupels.	
			Au+Ag.	Au.	Au+Ag.	Au.
a	14.63					
	14.63					
	14.53					
	14.21					
	14.50					
From slag and cupel	.05					
Total	14.55	(Hbd.).				
a_1	15.50		0.08	....	0.92	0.02
	15.52		.09	....	1.00	.02
	15.55		....	....	1.23	.04
	15.61		....	....	1.07	.03
	15.57		....	....	....	....
	15.53		....	....	....	....
Average	15.55		.09	0.04	1.05	.03
From slag and cupel	.07					
Total	15.62	(Allen).				
a_1	15.50		(a)	.02	(a)	.10
	15.48		....	....	(a)	.03
Average	15.49		....	.02	....	.06
From slag and cupel	.08					
Total	15.57	(Hbd.).				
b	17.76		.32	....	.87	....
	17.83		.28	....	.82	....
Average	17.79		.30	.02	.85	.03
From slag and cupel	.05					
Total	17.84	(Allen).				
b	17.69		(a)	.02	....	.03
	17.73		(a)	.02	....	.03
	17.47		(a)	.03	....	.03
	17.14[b]		(a)	.03	....	.03
Average	17.63		....	.025	....	.03
From slag and cupel	.055					
Total	17.685	(Hbd.).				

[a] Not weighed.

[b] Excluded from average as undoubtedly low.

TABLE V.—*Crucible assays of Cripple Creek telluride ores for gold alone*—Cont'd.

Main assay, Au.		Slags.		Cupels.	
		Au+Ag.	Au.	Au+Ag.	Au.
b_1	19.39	0.14		1.48	0.05
	19.53	.14		1.34	.06
	19.51			1.28	.03
	19.57			1.29	.04
	19.55				
	19.62				
	19.56				
Average	19.54	.14	0.04	1.35	.045
From slag and cupel	.085				
Total	19.625 (Allen).				
b_1	19.79	(a)			
	19.48	(a)			
Average	19.63		.02		.05
From slag and cupel	.07				
Total	19.70[b] (Hbd.).				

[a] Not weighed.

[b] Proof metal (19.85 mg. gold and 49 mg. silver) was crucibled, cupelled, and parted at the same time as these last two assays. The final gold was 19.84+0.07, or 19.91 in all, showing that in this case there must have been a marked retention of silver after parting. If a like correction has to be applied to the regular assays, the average drops to 19.64, almost exactly that of Allen.

In order to check the actual loss, including that by volatilization, the following cupellations were made with alloys corresponding to the above and about 25 grams in weight:

TABLE VI.—*Cupellation losses on proof alloy.*

	Taken.	Found.	Loss.		Recovered from cupels.	
	Milligrams.	*Milligrams.*	*Milligrams.*	*Per cent.*	*Milligrams.*	*Per cent.*
Ag	48.03	46.90	1.13	2.35	0.82	1.71
Au	15.79	15.70	.09	.57	.02	.12
Ag	55.37	54.77	.60	1.08		
Au	15.82	15.75	.07	.44		
Ag	63.65	62.27	1.38	2.17	1.09	1.71
Au	19.72	19.63	.09	.46	.02	.10
Ag	63.81	62.46	1.35	2.11	1.04	1.63
Au	19.74	19.64	.10	.51	.03	.15

When the above percentage recoveries are compared with corresponding ones for the alloy far richer in gold (p. 15, Table IV), it is seen, as might be expected, not only that there is a selective absorption of the metals, but also that the gold loss by cupellation is absolutely, and, relatively to the silver, greater in the richer gold alloy; but it is singular that whereas in the latter case practically all the lost gold (and silver) seemed to be recovered from the cupel, in the case of the rich silver alloy by far the greater part of the lost gold has been volatilized instead of absorbed. That a portion, and relatively a large portion, is always thus volatilized under similar conditions the results given in Table IX on page 21 clearly show, but there the volatilization loss, no matter at what temperature in the muffle, though very variable, is with one exception considerably below that by absorption. The explanation of this disagreement we are, unfortunately, unable to offer.

COMPARISON OF RESULTS.

Comparing the average results by combination wet and fire test and by fire assay alone, we have the following showing:

TABLE VII.—*Comparison of results by the two methods.*

Combination assay.		Fire assay.
a		H 14.55
	H [a]14.76	A 14.51
Average		[b]14.53
b		H 17.69
	H 17.71	A 17.84
Average		[b]17.75
a_1		H 15.57
	H 15.50	A 15.62
Average		[b]15.61
b_1		H 19.64 or [c]19.70
	H 19.47	A 19.62 19.62
Average		[b]19.63 or [c]19.64

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[a] Probably a little high from retained silver.

[b] Averaged from the results of both H. and A. by giving proper credit for the number of tests made by each

[c] See footnote to Table V, p. 17, for explanation of the alternative value.

From the above, it would seem to be be clear, as claimed by Furman, that for telluride ores of the composition of those of Cripple Creek the crucible fire assay gives results perfectly satisfactory, as compared with wet extraction. In three of the four ores assayed by us the advantage would seem to lie very slightly with the fire assay, but the determinations are too few in number and not sufficiently uniformly in one direction to permit us to regard this as demonstrated.

Because possibly some one may raise the objection that the fire assay failed to extract from the residues insoluble in the liquid reagents the whole of their gold contents, and that therefore the results do not prove the accuracy of the fire assay in comparison with the other, it is to be regretted that recourse had to be taken to the former to complete the wet assays, but there seemed no help for it. No reasonable person will entertain any doubt on the subject.

PART II. THE ERRORS IN GOLD ASSAYING.

CUPELLATION LOSSES.

ABSORPTION AND VOLATILIZATION.

That the loss of silver in assaying may be very marked is, of course, well known, particularly that loss which is due to too high heat during cupellation. That gold suffers similar losses, though to a much less degree, has been fairly well established by various workers. "That loss of gold takes place in cupellation if this is conducted at too high a temperature, or if the alloy is cupelled without quartation silver, is an already long-known experimental fact."[a] The data relating to gold are, however, not so satisfactory as those with respect to silver, and they are at times uncertain or even conflicting. It is in general said that the cupellation of gold may be carried out at a considerably higher temperature than that of silver, and the assayer is commonly advised to complete the final stage of the operation farther back in the muffle than the earlier stages. Some authorities insist on the absence of feather litharge at the end. There seems to be in the literature no adequate appreciation of the very marked effect that slight differences in temperature actually do produce on the yield of gold by cupellation, especially if the ore be rich, nor of the very considerable volatilization loss that accompanies cupel absorption if the heat is not kept at a minimum. Doubtless these facts are known to individual assayers, but they are not sufficiently emphasized in chemical literature, especially that to which practical assayers in this country usually have access. "Many yet believe that the degree of heat has little or no influence on the result."[b]

Our own experiments, which follow, were all made with proof gold and silver from the mint. The results are not therefore necessarily comparable with those obtained by assaying ordinary bullion, where the presence of copper is said to demand a higher temperature and to influence the gold loss.

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[a] Bodeman-Kerl's Assaying, translation by Goodyear, 1880, p. 194.

[b] Roessler in Dinglers Polytech. Jour., vol. 206, 1872, p. 186.

First, gold alone was cupelled in order to ascertain primarily the loss with increase of temperature, and, secondarily, how this loss was affected by the amount of lead used. Ordinarily six cupels were set in a row, from front to back of the 12 by 6 inch muffle, so that the front cupel always showed at the end abundant feather litharge, and the rear one was at the back end of the muffle. The cupellations were made in most cases with an altogether unnecessarily large amount of lead (25 grams), in order to duplicate as nearly as might be the conditions under which the assays described in Part I were cupelled. Table VIII shows these results.

Then quartation mixtures were cupelled and the silver as well as the gold losses determined (Table IX).

TABLE VIII.—*Losses of gold when cupelled without silver as affected by temperature and amount of lead.*

[25 grams in Series A and B, 5 grams in Series C.]

Series.		Gold taken.	Gold found.	Loss.		In cupels.	Volatilized.	Percentage of loss.	
								Absorption.	Volatilization.
		Mgs.	*Mgs.*	*Mgs.*	*Per cent.*	*Mgs.*	*Mgs.*		
A.	1	30.58	30.47	0.11	0.36	0.15	....	136	....
	2	30.32	29.96	.36	1.19	.29	0.07	80	20
	3	30.63	30.09	.54	1.76	.57	....	105	....
	4	30.45	29.30	1.15	3.78	.89	.26	77	23
	5	30.16	28.90	1.26	4.17	1.17	.09	93	7
	6	30.66	29.30	1.36	4.43	1.25	.11	92	8
B.	1	10.34	10.31	.03	.29	....	....	....	....
	2	10.25	9.77	.48	4.68	....	....	....	....
	3	10.29	10.15	.14	1.36	Litharge formed faster than it could be absorbed during much of the time, yet the furnace ran at an unusually high heat.			
	4	10.27	9.20	1.07	10.42	....	....	....	....
	5	10.17	8.56	1.67	16.43	....	....	....	....
	6	Lost	....	....	....	....	....	....	....
C.	1	10.36	10.33	.03	.29	5 grams lead.			
	2	10.31	10.23	.08	.78				
	3	10.31	10.16	.15	1.45				
	4	10.17	9.87	.30	2.95				
	5	10.29	9.84	.45	4.37				
	6	Lost	....	....	....				

TABLE IX.—*Losses of gold and silver when cupelled together.*

[25 grams lead.]

Series.		Gold taken.	Gold found.	Gold loss.		Silver taken.	Silver found.	Silver loss.		In cupels.				Percentage of loss.			
										Absorbed.		Volatilized.		Absorbed.		Volatilized.	
										Au.	Ag.	Au.	Ag.	Au.	Ag.	Au.	Ag.
		Mgs.	*Mgs.*	*Mgs.*	*Per cent.*	*Mgs.*	*Mgs.*	*Mgs.*	*Per cent.*								
A.	1	30.06	29.91	0.15	0.50	90.51	88.97	1.54	1.70								
	2	30.40	30.03	.37	1.22	90.19	86.82	3.37	3.73								
	3	30.60	29.89	.71	2.32	90.74	85.71	5.03	5.51								
	4	30.07	28.94	1.13	3.76	90.67	83.73	6.94	7.66								
	5	30.61	29.42	1.19	3.89	90.75	83.51	7.24	7.98								
	6	Lost.															
B.	1	15.56	15.53	.03	.19	45.06	44.20	.86	1.91	0.02	0.70	0.01	0.16	67	81	33	19
	2	15.14	15.08	.06	.40	45.19	43.70	1.49	3.30	.05	1.17	.01	.32	83	78	17	22
	3	15.15	14.92	.23	1.52	45.41	43.53	1.88	4.14	.12	1.19	.11	.69	52	63	48	37
	4	15.44	15.12	.32	2.07	45.30	42.68	2.62	5.78	.22	1.63	.10	.99	67	62	33	38
	5	15.52	15.12	.40	2.59	45.59	42.61	2.98	6.55	.27	2.09	.13	.89	67	70	33	30
	6	15.39	15.02	.37	2.40	45.05	42.07	2.98	6.61	.27	2.13	.10	.85	73	71	27	29
	Mean													68	71	32	29
C.	1	10.67	10.62	.05	.47	30.33	29.67	.66	2.17								
	2	10.57	10.40	.17	1.61	30.64	28.90	1.74	5.68								
	3	10.53	9.99	.54	5.13	30.42	27.32	3.10	10.19								
	4	10.63	9.50	1.13	10.63	30.52	25.64	4.88	15.99								
	5	10.60	9.28	1.32	12.46	30.38	24.81	5.57	18.34								
	6	10.21	8.93	1.28	12.53	30.44	24.75	5.69	18.69								

The foregoing tables show most strikingly the effect of increasing temperature on the loss of gold (and silver) and that this loss with pure gold is almost wholly by cupel absorption. A difference of position in the muffle amounting to no more than the width of a cupel is of great moment. The percentages given in the last two columns of Series A, Table VIII, and of Series B, Table IX, are of course subject to considerable probable error because of the difficulty of weighing such small beads to hundredths of a milligram and the probability of losses inherent in the operations by which they were obtained. Further, because of the probable retention of traces of lead by the large gold beads (see p. 24), the volatilization figures are, if anything, too low and those for absorption too high.

It is clear that the following statements are far from correct:

"A high temperature has no ill effect, the loss of gold in cupellation being so small that it need not be considered. It is about balanced by the silver left in the gold after parting. The cupellation loss is about 0.07 per cent."[a]

"The loss of gold by cupellation is insignificant (about 0.7 per 1,000), compensated moreover by the small quantity of silver which the gold retains after parting."[b]

"All the silver lost is absorbed by the cupel."[c]

Our experience goes to show that, as a general direction, the following should be modified, for with pure gold and telluride ores no higher heat is needed than for silver cupellation.

"A high heat is maintained throughout the operation [cupellation] and especially at the time of brightening, that is to say, a higher degree than is admissible in a silver assay . . ."[d]

The average loss named in the first two of these extracts is from three to seven times less than the lowest of those in Tables VIII and IX—those suffered at the lowest permissible limit of temperature.

Though not connected with the present discussion, it is impossible to see why the following, credited to Aidarow, should be true:

"The gold, however, only soaks into the cupel when it has been scorified with lead beforehand. If gold is added to lead that is already fused on the cupel, no loss of gold takes place on cupellation."[e]

That a small but appreciable portion of the total loss is due to volatilization the results of Series A, Table VIII, and Series B, Table IX, clearly show. That such loss occurs is mentioned by some writers;[f] but most writers make no mention of it. According to Rose,[g] 10 per cent of the total loss in bullion assay is by volatilization, a proportion roughly agreeing with the returns in Table VIII, Series A, final columns.

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[a] Beringer, A Textbook of Assaying, 1890, p. 128.

[b] Campredon, Guide Pratique du Chimiste Métallurgiste, 1898, p. 689.

[c] Campredon, ibid., p. 304.

[d] Aaron, Assaying, 1900, p. 36.

[e] Bodeman-Kerl, Assaying, translated by Goodyear, 1880, p. 171.

[f] Makins, Quart. Jour. Chem. Soc., vol. 13, 1861, p. 97; Roessler in Dinglers Polytech. Jour., vol. 206, 1872, p. 189; Ricketts and Miller, Notes on Assaying, 1897, pp. 128 and 129.

[g] Metallurgy of Gold, p. 479.

That gold volatilizes slowly if kept above its melting point Napier has shown,[a] but this condition does not ordinarily, if at all, obtain after the bead has brightened, so that the direction that it is quite safe to leave gold beads in the muffle after brightening for almost any length of time seemed probably justified. To test the point, however, a number of trials were made by cupelling several beads simultaneously and taking them out at intervals of one-half, five, and twenty minutes after pushing them back in the muffle to brighten. No constant losses were suffered by those left in for the longer periods, but curiously enough there seemed to be a slight tendency to increase in weight. To what this could be attributed is not clear.

On their face the results of Series C, Table VIII, as compared with Series B of the same table, seem to indicate that the amount of lead exerts a very marked effect on the gold loss. Roessler[b] is fully persuaded from his own table of tests that this is generally true. But compare for a moment the three series of Table IX. The same amount of lead was used in them all (25 grams) and the absolute losses of gold with 30 mgs. and with 10 mgs. were practically identical, while with 15 mgs. (Series B) they dropped to about one-third. Here the only seemingly probable explanation is that the temperature throughout the muffle must have been appreciably lower with B than with A and C. Hence it is not improbable that a similar explanation may be the proper one to adopt for the low results of Series C in Table VIII. The cause is certainly not conclusively shown, and it has been made plain that slight differences in temperature produce marked effects.

The final columns in Series B, Table IX, are of interest as showing that with quartation alloys not only is the volatilization loss of gold greater than when pure gold is cupelled, but also that the ratio of volatilization loss to absorption loss is about the same for both gold and silver, or, roughly, as 30 to 70. We regret that similar comparisons were not made for the other series. It is hoped that at some future time opportunity may offer to test this and other points of interest more critically. For the present, however, this is impossible owing to the enforced abandonment of the Survey's fire-assay laboratory. It is largely due to this latter fact that the work herein described is rather fragmentary and not altogether satisfying.

RETENTION OF LEAD BY CUPELLED BEADS.

Inasmuch as in hardly a single case did our corrected assays on proof metal show more than was weighed at the start, even at the lowest heat, with full feather litharge, it did not seem necessary to assume the presence of lead in the beads obtained. Nevertheless, in one case a number of them from the same series of assays were dissolved in aqua regia together, the gold precipitated, and the solution evaporated to a few drops. By exercise of the utmost care it was possible to detect a minute quantity of lead, too small, perhaps, to have influenced the results to any appreciable extent.

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[a] Quart. Jour. Chem. Soc., vol. 10, 1858, p. 229.

[b] Dinglers Polytech. Jour., vol. 206, 1872, p. 188.

Later the following experiments were carried out:

Experiment 1.—Three beads of proof gold, weighing, respectively, 30.14, 50.40, and 10.35 mgs., were cupelled with 2 grams of lead each, in the ordinary way, and weighed after boiling with dilute hydrochloric acid to remove any film of lead oxide or particles of litharge-soaked bone ash. They were then dissolved together in aqua regia, evaporated, diluted with sulphurous acid, the solution filtered and evaporated till fumes appeared. The residue, consisting of lead sulphate and a little metallic gold, was transferred to a filter after taking up with alcohol, the sulphate extracted by ammonium acetate, the lead reprecipitated by hydrogen sulphide, reconverted into sulphate, and weighed. The weight was 0.0004 gram, equivalent to 0.3 per cent of lead.

Experiment 2.—Three beads of very nearly the same weights as those first acted on were treated in a similar manner, except that they were left in the muffle twenty minutes after brightening. The amount of lead recovered from all three together was 0.37 per cent.

This shows clearly, as had our earlier experience, that the error, though of some magnitude, is not lessened by leaving the beads in the muffle for a considerable time after brightening. It should be said that the sulphate weighed was certainly of lead and not silver. The percentages above given are, however, to be regarded as approximate only.

LOSSES OF GOLD IN SLAGS.

From a statement in Fulton's paper, "Assay on telluride ores,"[a] we were led to expect much greater losses of gold in the slag than appear from the tables in Part I of this bulletin. Fulton says that these are much greater with Cripple Creek telluride ores than with ordinary gold ores. They appear, however, so far as our own work goes, to be slight. We have suggested on page 14 a possible explanation for his higher losses.

ERRORS IN PARTING.

STRENGTH OF ACID.

Most diverse is the practice in parting as to the strengths of acid employed. Vauquelin seems to have first used acid of 1.16 and 1.26 specific gravity, and these are the strengths most frequently recommended to-day. But there are not wanting those who prescribe other strengths, or who reverse the order of application—that is, employ the stronger acid first—or who are content with acid of uniform strength.

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[a] Jour. Am. Chem. Soc., vol. 20, 1898, p. 589.

INCOMPLETE EXTRACTION OF SILVER.

Not less diverse are the statements as to the completeness of the silver extraction. Campredon puts the average silver retention for bullion assay, tested upon an aggregate of 100 cornets, at 0.0002 gram. According to Beringer,[a] the surcharge may amount to 0.05 per cent. In Brown's Assaying (p. 396) it is said that "A small amount of silver will always remain in the cornet, no matter how carefully the manipulations may have been conducted." On the other hand, Ricketts and Miller[b] say that the inaccuracy due to silver retention in parting can be avoided by careful work. Later, however, they say (p. 128) with respect to gold bullion, "On the other hand, the gold always contains some silver and occluded gases." That cornets retain occluded gases was proved by Graham,[c] and Varrentrapp showed that the amount varies with the temperature of annealing.[d]

Our own experience in the present work is that while sometimes by dissolving a number of beads together traces of silver were detected, quite as often none were found. This was before we learned the need for more than two or three boilings with acid. We believe that some of the unfavorable results reported by various writers may have been due to insufficient treatment with acid and inadequate washing. Not infrequently the direction is given to wash three times with water. That this is insufficient for such cornets as are obtained in bullion assay our own tests have proved to us. (See further, p. 27.)

There is great lack of agreement, too, as to the best gold-silver ratio in the quartation alloy. For instance, Chaudet and Kandelhardt are credited in Bodeman-Kerl[e] with the statement that a gold-silver alloy with 2½ parts of silver retains less silver when parted with nitric acid than an alloy with 3 parts. The same authority attributes to Pettenkofer the statement that the separation can succeed well with as little as 1¾ parts of silver to 1 of gold. Rammelsberg is quoted[f] to the effect that pure nitric acid dissolves all the silver out of an alloy containing 80 per cent and more of silver and leaves all the gold behind; and, on the contrary, the separation is imperfect with a proportion of from 15 to 80 per cent of silver.

IMPURITIES IN ACID.

Of course, if the acid used for parting contains certain impurities, losses will occur. The impurity most to be guarded against is hydrochloric acid or chlorine. Bodeman-Kerl[g] mention also sulphuric and sulphurous acids. Rose[a] ascribes, on the basis of his own tests, 8 per cent of the total loss in a gold assay to the solvent action of the acid, without specifying further. Lenher[b] confirms the statements of several authors as to the solubility of gold in a hot mixture of strong sulphuric and nitric acids, and that on dilution with water it precipitates, this precipitation being supposedly brought about by nitrous acid formed from the nitric acid. He also shows that the sulphuric-nitric acid mixture dissolves gold even at 0° C.

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[a] A Text-book of Assaying, 1890, p. 129.

[b] Notes on Assaying, 1897, p. 109.

[c] Philos. Trans. Roy. Soc., 1866, p. 433.

[d] Rose, Metallurgy of Gold, p. 481.

[e] Goodyear's tranlation, 1900, p. 183.

[f] Ibid., p. 184.

[g] Ibid., p. 187.

ACTION OF NITROUS ACID.

The statement, which, according to Makins, can be traced to Berzelius, is met with in several places that loss of gold ensues in parting from the solvent action of nitrous acid; and Makins,[c] by repeated boilings of assay gold with nitric acid of specific gravity 1.25 and 1.35, was able to establish a steady loss which he attributed to nitrous acid, though the proof is by no means convincing, as he does not clearly show the entire absence of traces of hydrochloric acid in his nitric acid, nor of silver in his cornets, nor did he evaporate the filtrates and prove that they contained gold. The active agent could not be nitrous acid formed from the solution of the quartation silver for its formation must have practically ceased after the second or third boiling. Van Liew[d] obtained astonishing results. He condensed nitrous acid, which he prepared by reducing potassium nitrate with lead and treating the nitrite with sulphuric acid, in a 30 per cent solution of nitric acid in which had been placed leaf gold. At 15° C. about 1 to 2 per cent of the gold was found to have dissolved, and upward of 38 per cent at 82° C., and 51.9 per cent at an undetermined lower temperature.

In order to obtain light on this point one of us prepared nitrous acid and tested its effect on spongy gold. Cold aqueous solutions were obtained by the method of Lunge from starch and nitric acid.

Experiment 1.—Twenty-five c. c. of the solution, containing 0.032 gram HNO_2 and 0.401 gram HNO_3 per cubic centimeter, was placed in a pressure bottle with very thoroughly washed spongy gold and left in contact for thirty-six hours, the final temperature being about 30°. Evaporation of the filtrate to dryness showed a small, yellowish-white residue, which proved to be mostly organic (a blank test gave the same result). When this was heated to redness a faint purple stain remained. This, when dissolved in a few drops of aqua regia and tested with stannous chloride, showed a trace of gold.

---

[a] Metallurgy of Gold, p. 479.

[b] Jour. Am. Chem. Soc., vol. 26, 1904, p. 552. Lenher in this paper gives interesting data on the solvent action on gold of a number of bodies other than the halogens, but they are outside the present discussion.

[c] Quart. Jour. Chem. Soc., vol. 13, 1861, p. 99.

[d] Eng. and Min. Jour., vol. 69, p. 498.

Experiment 2.—The solution was more concentrated, holding 0.0548 gram HNO_2 and 0.075 gram HNO_3 per cubic centimeter. A trace of gold was found.

Experiments 3 and 4.—In each of these 10 c. c. of solution, containing 0.062 gram of HNO_2 and 0.219 gram of HNO_3 per cubic centimeter, was sealed in a tube with spongy gold and heated for seven hours at about 150°. No gold was found in either case.

It is difficult to see how the above conditions can have differed materially from those in Van Liew's experiments; nevertheless, nitrous acid was made from pure potassium nitrate and its action on spongy gold observed at a temperature of about 70° to 80° in pressure bottles. No solution of gold could be proved.

In all of the above experiments the acid was filtered through a close plug of ignited asbestos before testing for gold.

The results of these severe tests show that solvent action by nitrous acid during an assay need not be considered. The reported precipitating action of nitrous acid in dilute solution (see above, p. 26) seems to be in direct opposition to such solvent action. Van Liew's abnormal results must have been due to using a nitrate containing chloride as the source of his nitrous acid.

ACTION OF NITRIC ACID.

To test the possible effect of nitric acid itself the following experiments were made:

Four portions of pure gold were cupelled with three times their weight of silver and 5 grams of lead each. Five boilings with acid, with intervening washings, were needed to extract the silver to such an extent that an ordinary test failed to show it longer in the extracts. Then No. 1 was boiled with 20 c. c. HNO_3 for fifteen minutes, washed, annealed, and weighed. No. 2 was boiled two periods of fifteen minutes each with acid and properly washed, then annealed and weighed. With Nos. 3 and 4 the boiling with acid was repeated two and three times, respectively, the duration of acid treatment in case of No. 4 lasting between one and two hours. The following table shows that no systematic losses appear, and that in the most severe test no loss whatever occurred:

	Taken.	Found.	Loss.
	Mgs.	*Mgs.*	*Mgs.*
1	250.27	249.99	−0.28
2	250.23	250.29	+ .06
3	250.57	250.53	− .04
4	250.38	250.38	.00

The acid thus used was tested for gold as follows: It was evaporated in clean porcelain dishes, the residues were moistened with a few drops of water and wiped out clean with small pieces of filter paper, these were wrapped in lead cornets to which a tiny piece of silver was added, cupelled, and parted.

No. 1 gave no gold.[a]

No. 2 gave 0.01 mg. gold.

No. 3 gave 0.01 mg. gold.

No. 4 gave no gold.

The acid used for parting was also carefully tested for gold after first precipitating the silver. That from the four first partings combined gave no gold. That from the second gave 0.02 mg. gold in all. This gold may have been float gold, though the utmost care was taken to guard against this source of error.

From the above it is plain that the losses in parting with pure acid, whether traces of gold really dissolve or not, are negligible in an ore assay at least.

In conclusion it may be said that the gold beads, after the repeated treatments with nitric acid detailed on page 27, were dissolved in aqua regia and the solutions tested for silver with the greatest care, both before removal of the gold and afterwards. In not a single case could the slightest trace of silver be detected.

SUMMARY OF RESULTS.

Not all of the conclusions here summarized are to be regarded as fully established, while some are but confirmations of earlier statements by others. More work is needed along certain lines, for there is more than one obscure point connected with the fire assay that needs greater attention than we were able to give it. To what extent the results for cupel losses by different workers will be influenced by a difference in the quality of the cupels used there is, unfortunately, no means of determining. The possibility of such a disturbing influence must always be borne in mind.

It is clearly established that the fire assay by crucible for gold telluride ores gives results which are quite equal to those obtained by the wet way, provided due corrections are made for slag and cupel losses.

The gold loss in the slag is very small and generally negligible with the charge used by us,[b] but the cupel losses are very appreciable, and considering the far greater value of gold than of silver, weight for weight, it may be doubted whether the statement that "The loss of gold in the assay of any ore, except when extremely rich, is too small to require correction"[a] is justified when very exact work is called for. Much depends on what is meant by "extremely rich." Doubtless the ores treated of in Part I fall within this category, but the losses are there so detectable that correction seems called for with ores far less rich. In view of the very appreciable errors that always occur and which it is quite impossible to wholly allow for in any ordinary assay, it seems that those who demand an assay balance weighing to less than the hundredth of a milligram are decidedly straining at a gnat if they are willing to swallow the camel of an uncorrected assay.

---

[a] The absence of gold here shows that the large apparent loss in weight of the cornet, as shown by No. 1 of the table above, was not due to solution of gold.

[b] It is quite conceivable that some ores, differing from ours in the character of their gangue, may give slags that have greater solvent action on gold.

The cupellation loss of gold by volatilization is generally small as compared with that by absorption, and at a temperature allowing the formation of abundant feather litharge is negligible, or perhaps compensated by retention of lead (Table IV), but the case is otherwise at high temperatures (Tables VIII and IX), when it may average one-half of that by absorption in the case of a quartation alloy. The results of Table VI seem to contradict the first statement, for they show a much greater apparent loss by volatilization than by absorption.

The loss of gold by absorption is a very important one, and is influenced, far more than is generally supposed, by slight changes in temperature. It is greater with pure gold and alloys poor in silver than with alloys rich in silver.

From a limited number of tests it appears that the ratio of volatilization loss to absorption loss for quartation alloys at higher than the normal temperature of cupellation is about the same for both gold and silver, or roughly, 30 to 70. This point needs further testing.

Our experiments failed absolutely to show the need for a higher temperature at the end of cupellation with gold beads than with those of silver. The most exact results were obtained when feather litharge was still abundant at the time of brightening.

Furthermore, it is altogether unnecessary to leave gold beads in the muffle for some time after brightening in order to remove the last of the lead, for there is no loss in weight from so doing, but if anything a very slight tendency to increase.

Our results on absorption as influenced by the amount of lead used in cupellation are inconclusive.

The error caused by retention of lead in the beads is one of some magnitude if the results of two careful tests are to be depended on, which showed 0.30 and 0.37 per cent, respectively, of lead. The amount of this retention is not lessened by leaving the beads in the muffle for some time after brightening.

Silver can be completely extracted from quartation alloys by nitric acid, but more than two repetitions of the acid treatment and subsequent washing are called for if any certainty of complete extraction is to be expected.

---

[a] Ricketts and Miller, p. 110.

Tests made with mixtures of pure nitrous and nitric acids show that the solvent action of the former acid is so slight, if indeed there is any at all, that it need not be considered as a possible disturbing factor in parting.

Similarly it was shown that the losses in parting with pure nitric acid, whether traces of gold really dissolve or not, are quite negligible, in an ore assay, at least.

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